Progress report on analysis of historical fish and zooplankton population dynamics

Bryan Manly and Mike Chotkowski

Disclaimer: This document (including its appendices) is a progress report that summarizes steps taken to date. The analyses reported here should be viewed as model examples of the methods being developed. They are not final, nor should they be relied on for any purpose. The final results will be based on improved methods and may lead to different conclusions.

<u>Context</u>

In the 2005 "POD" program, analysis of historical fish and zooplankton dynamics are assigned to this element (#2i). Phytoplankton dynamics have been and are being addressed in ongoing work by Alan Jassby and others (see element #4c, "Phytoplankton primary production and biomass in the Delta"). Benthic biomass dynamics are dealt with in element #4d ("Retrospective analysis of long-term benthic community data".

<u>Introduction</u>

In this element we examine the historical record of the pelagic fish and zooplankton monitoring surveys in the upper San Francisco estuary from their beginnings through the period of the recent declines. The trawls effectively sample only YOY of most fish species, so the investigation is generally limited to that age class. Objectives:

(1) Describe long-term patterns in individual pelagic species catches, including trends, step changes, and changes in distribution among sampling stations.

(2) Describe joint patterns in the catch of pelagic species to evaluate the extent of coincidence in trends and step changes

(3) Describe long-term patterns in common littoral fish species catches to see whether they contrast with pelagic species

(4) Investigate the contribution of factors known to affect catch of some species, such as seasonal pulses in river discharge, and also factors hypothesized to affect trawl catch, such as SWP and CVP exports.

This is not a conventional report, but rather a shorthand account of ongoing work that has been done in parcels by Bryan Manly. Work to date is described in detail in four appended draft reports, with some explanatory notes given below. Major caveats:

(1) We have not developed any analyses incorporating zooplankton variables yet, because we did not have access to debugged zooplankton monitoring datasets until the end of September.

(2) We have not incorporated predictive variables derived from DSM2 PTM modeling work released by DWR in September (and described in a separate report appended to the "POD" package entitled "Particle tracking model results 2h – T Sommer.pdf". We are currently digesting these data, and we expect to our final 2005 report (expected in November) to include analyses incorporating them.

(3) We have not yet produced an analysis of changes in geographical distribution of any species. Kelly Souza has produced figures (attached to the "POD" package as "Dist&Abund_Graphics.xls") showing changes in the contribution of several regions to the annual FMWT index for the common species and age categories. We will allow time trends explicitly associated with geographical areas in the next revision of our work.

(4) We have focused on delta smelt in the most recent parcel of individual-species work. The other pelagic species will be dealt with in time to be included in the the final report.

(5) We will not complete an analysis of littoral fishes in 2005.

To date our full attention has been focused on the improvement of the methods, not on interpreting the results.

<u>Notes on Draft Report A ("Analyses A" below)</u>
This document reports Bryan's initial analysis of the FMWT data. It includes an exploratory analysis of the FMWT species variables and explains the reasons for the selection of the log-linear methods used in succeeding reports. In this report, the main objective is to fit time trends and a step change fixed at 2001-2002 (i.e. first year of new regime is 2002). In this analysis, a step-change effect significant at the 5% level was found for ten of eleven species, including eight negative effects and two positive effects.

<u>Notes on Draft Report B ("Analyses B" below)</u>
Report B improves methods used in the original FMWT analysis and applies the refined methods to both the FMWT and to the Bay Study MWT and OT. The revised log-linear model analyses add quarterly seasonal effects and geographical area effects. Although the log-linear model analyses employed an assumed step change at 2001-2002, a preliminary, example change-point analysis is presented which attempts to locate step changes.

The example is based on the log-linear model for threadfin shad in the BSMWT, which has a highly significant 2001-2002 step effect. Based on a null model containing no step change effects, 1000 new data sets were generated by bootstrapping the residuals, and these were compared with the original data. This analysis revealed that the assumed 2001-2002 step change was not the most significant change-point among all those possible. The demonstration revealed that the asymptotic theory used to interpret the log-linear models is not very effective with the threadfin shad data (and presumably others), presumably because of the large number of zero and small observed counts.

It is concluded that the evidence for a step change in fish numbers between 2001 and 2002 is not as clear from the Bay Study data as it was from the FMWT data. In particular, for the Bay Study all of the evidence for step changes comes from log-linear model analyses, but the preliminary simulation study noted above suggests that the standard methods for assessing the significance of these step effects may not be reliable for data of the sort these monitoring studies provide.

Notes on Draft Report C ("Analyses C" below)

This document expands the change-point analysis. A Monte Carlo approach allowing for trends in the data is developed that relies on determination of the distribution of estimated step change parameters when no step changes exist, and on determination of the distribution of the most significant of these estimates. On data sets containing no step changes this method performs exactly as it should. When applied to the FMWT and Bay Study data, it became apparent that the significance of estimated step changes is far less from the Monte Carlo method than it is using the usual methods of log-linear modeling. Nevertheless, there are still many significant estimated changes with the real data, even when significance is assessed using the more conservative Monte Carlo method. These step changes are generally not between 2001 and 2002, suggesting that the observed 2001-2002 step changes are not particularly unusual in context. (However, we weren't completely satisfied with the analysis, so it is being revisited. See below.)

Notes on Draft Report of 30 August ("Effects of hydrological, environmental, and other variables on delta smelt counts" below)

This document represents the first analysis that includes hydrologic variables and focuses specifically on delta smelt. Hydrologic variables included variants of four basic Dayflow variables and two derivatives: Sac River discharge, Yolo Bypass flooding days, San Joaquin River discharge, total (SWP + CVP) exports, export-inflow ratio, and total exports-SJR discharge ratio. Environmental variables (temperature, conductivity, and Secchi distance) recorded at the time of each trawl haul were also included. Models also allowed up to quartic time trends, geographic area effects, and step changes (particularly between 2001 and 2002). Unfortunately, the hydrologic variable suite had many strong positive and negative correlations, a situation which may create difficulties interpreting the associations suggested by the final fitted model.

Because plots of CPUE vs the hydrological variables indicated various relationships, some apparently non-linear, it was decided to include quadratic terms in each of the hydrologic variables to allow a curvilinear fit. Variants of each basic variable were tested against one another in series of models, each containing one variant.

The resulting log-linear model containing the best of each hydrologic variable variant and the other predictors was then stripped of non-significant effects, resulting in an equation with 13 estimated coefficients for hydrologic and environmental effects. At that point a step effect between 2001 and 2002 was added into the model and found to be significant by the usual t-test.

Bootstrapping revealed that the significance of the estimated coefficients was generally exaggerated by using standard t-tests. This allowed the removal of additional non-significant hydrologic effects, as well as the 2001-2002 step change. However, step changes for 1981-82 and 1998-99 remained significant and apparently should be included in the fitted model.

A second bootstrap provided assurance that the modified model is reasonable. The modified model includes area effects, time trends, Sacramento River discharge, Yolo Bypass flooding days, E/I, total exports/SJR discharge, total exports, Secchi depth, conductivity, and step changes for 1981-82 and 1998-99.

Notes on outstanding issues

At meetings on 9/19 and 9/20, a number of issues was discussed. The discussion led to several decisions. We decided to:

(1) Complete the analysis of change points before the log-linear model analyses, to make it possible to separately fit the log-linear models to distinct segments in the time series between change points.

(2) Use different methods for means of individual and grouped-species cases of the change point analyses (Bryan's CUSUM method for individual species, the Monte Carlo method for grouped-species cases). We will also review Mike's ad hoc CUSUM-like moving average method for grouped species to see whether it offers anything not provided by the other methods.

(3) Report change point analyses of individual species and grouped-species for two cases: (i) raw, and (ii) adjusted to account for basic hydrology (i.e., with SJR1 + SAC1 – total exports).

(4) Estimate time trends separately for geographical regions in log-linear model analyses.

(5) Limit the grouped-species case to a grand grouping containing all the appropriate species and age-class categories. Alternate groupings based on seasonal age congruence, diet similarity, and natural history features were considered in principle and rejected for the current investigation.

(6) Proceed with separate log-linear modeling analyses that include only time trends on segments of raw individual species data between identified change points.

(7) Investigate the sensitivity of the trend coefficients to the degree of the trend polynomial.

(8) Proceed with analyses for individual FMWT species including hydrology predictors that might shed some light on POD hypotheses

a. "primary" hydrology effects updated to include WY2005 data (SWP and CVP exports and sum of river discharges, or a PCA formulation)
b. "secondary" hydrology effects (e.g. SJR non-entrained discharge, from DSM2 studies)

(9) Review the constitution of the hydrology predictors. Most are averages over intervals of several months. Other formulations may be more appropriate.

(10) Proceed with analyses for individual FMWT species including ecology predictors that might shed some light on POD hypotheses

a. zooplankton (all as spring+summer indices)
   i. Eurytemora + Pseudodiaptomus
   ii. calanoid copepodites
   iii. total mysids
   iv. Daphnia
   v. Sinocalanus + Limnoithona ("bad food" index)
b. total YOY centrarchid abundance or other variables from FWS JFMP

We expect to complete most of these items in time to report on them at the public meeting on November 14th, and to complete a final 2005 report by the end of the year.

Analyses A: Log-Linear Modeling, Linear Regression, and Principal Components Analysis for Fall Midwater Trawl Fish Counts, 1967-2004

Bryan F.J. Manly
Western EcoSystems Technology Inc.
bmanly@west-inc.com

Contents

Summary 2

Introduction 4

The Data 5

Log-Linear Models on Counts 6

Regression Analysis on Logarithms of Mean Counts 7

Principal Components Analysis 8

Results for Log-linear Modeling 9

Results for Linear Regressions on Logarithms of Counts 9

Results for Principal Components Analysis 13

Conclusion 17

References 19

Appendix A: Data Used for Log-linear Modeling 20

Appendix B: Estimated Expected Fish Catch Per Tow 32

Summary

- Log-linear modeling, linear regression, and principal components analysis were used to examine the question of whether there was a step change between 2001 and 2002 in the abundance of some or all of ten groups of fish caught in fall midwater trawls (FMWT) in the Sacramento-San Joaquin Delta. The ten groups included nine species of fish (delta smelt, American shad, threadfin shad, longfin smelt, splittail, striped bass, white sturgeon, white catfish and chinook salmon), with separate counts for striped bass aged 0 and 1.

- The data available consisted of the results obtained from the FMWT sampling in 14 different geographical areas in the delta, for the years 1967 to 2004. No sampling was carried out in 1974 and 1979.

- For log-linear modeling each of the fish species was considered individually, with the data consisting of the total catches in each of the different geographical areas in the delta, for each of the sampled years. The models considered allowed for up to quartic polynomial trends with time, and effects due to the area of the Sacramento-San Joaquin Delta that was sampled. Each of the fish species sampled displayed significant time trends in the numbers captured. With the exception of striped bass aged 1 (for which the step change parameter was nearly significant) a parameter measuring a step change in abundance between 2001 and 2002 was significantly different from zero at the 5% level. There were eight negative estimates (for delta smelt, threadfin shad, longfin smelt, splittail, striped bass aged 0, striped bass aged 1, white sturgeon, and chinook), indicating a drop in numbers, and two positive estimates (for American shad and white catfish), indicating an increase in numbers.

- By treating the data as coming from stratified sampling, with the 14 geographical areas for strata it is possible to estimate a population catch per unit effort (CPUE) for the whole of the Sacramento-San Joaquin Delta, for each fish group in each sampled year. The logarithms of these estimates was analyzed by linear regression, allowing for up to quartic trends with time and a possible step effect between 2001 and 2002. Based on this approach estimated step effects are in the same direction as was found by log-linear modeling, but less extreme and with only two significant effects.

- A principal component analysis was based on the correlation matrix for the natural logarithms of the CPUE estimates. There are 45 correlations between the pairs of these variables, of which 19 (42%) are significantly different from zero at the 5% level. These significant correlations are all positive, and involve all fish groups except American shad. The highest correlation is 0.68 between white sturgeon and striped bass aged 0.

- The first three principal components (PC1 to PC3) account for 67.3% of the variation in the data set. PC1 is an index of the overall abundance of all fish species, while PC2 and PC3 measure various contrasts between the abundance of different groups of fish.

- Regression models were fitted to each of the principal components to represent the trend with time and a possible step change between 2001 and 2002. Trends terms were significant for PC1 and a step change effect was nearly significant at the 5% level. For PC2 and PC3 the trends and step change parameters are significant. PC1 indicates a continuous decline in overall fish abundance from 1967 to 2001, followed by a drop to a lower level than was ever seen before for 2002 to 2004. PC2 shows upwards and downwards trends from 1967 to 2001, at which point an upward trend was evident. There was a drop in the index at that point. Although PC3 shows a significant step increase between 2001 and 2002 this was not maintained in 2003. Therefore for this index the evidence for a step change is not really clear.

- It is concluded that the results of the log-linear modeling of the individual species fish abundances are consistent with the hypothesis that there was a general stepwise change in the numbers caught between 2001 and 2002, with most changes being downward, and with the change being considerable for most of the species. Step changes are not so apparent from a regression analysis on logarithms of yearly CPUE, although estimates of effects are in the same direction as for log-linear modeling. Nevertheless, a principal component analysis does indicate community level changes in the fish populations, with a sharp drop in general abundance between 2001 and 2002, and an abrupt change in the relative abundance of some fish species.

Introduction

The data considered for the analyses described here are counts of fish obtained from the fall midwater trawl (FMWT) in the Sacramento-San Joaquin Delta, California, for the years 1967 to 2004. Counts were available for ten groups of fish in 14 different sampling areas. The ten groups included nine species of fish (delta smelt, American shad, threadfin shad, longfin smelt, splittail, striped bass, white sturgeon, white catfish and chinook salmon), with separate counts for striped bass aged 0 and 1. The sampling areas are shown in Figure 1.

Log-linear modeling (McCullagh and Nelder, 1989) is designed specifically for the analysis of count data. The first analysis carried out therefore involved fitting log-linear models to the fish counts, with an allowance for different sampling areas and time trends that may vary from area to area. There is particular interest in whether there were step changes in abundance between 2001 and 2002, and the models therefore included a parameter to allow for this. The ten fish groups were analyzed separately. For each group models were considered that allow for different mean counts in different sampling areas, with time trends that may be linear, quadratic, cubic or quartic and may also vary with the sampling area. The approach involved fitting the most complicated model allowed, with quartic time effects varying from area to area, and then removing non-significant terms ($p > 0.05$), one by one. The resulting model containing significant effects was considered to be a reasonable representation of the trend in the data. It was then modified by allowing a step change in the expected values from the model for samples taken after 2001. This allowed the size of step changes to be estimated after allowing for area and trend effects.

For some species the counts from FMWT sampling are quite small and the most complicated model allowed either could not be fitted (i.e., the iterative estimation process did not converge) or there were problems with the estimation of some parameters. In these cases a model allowing for area effects only was considered first, and significant trend effects were added to this model one by one until either all significant terms were included in the model or there was a problem with adding further terms to the model. Again, once a model allowing for area and trend effects was chosen, this was modified by allowing for a step change in fish abundances between 2001 and 2002.

The estimated models from the log-linear model analyses were used to produce mean yearly catches per tow from the FMWT for each of the ten fish groups for the whole of the Sacramento-San Joaquin Delta. For this purpose the data were treated as coming from a stratified sample, with the strata being the 14 geographical areas shown in Figure 1. The sample from each area in each year was treated as being approximately equivalent to a random sample from the area, and each area was regarded as having approximately the same size. Estimation used the standard equations for stratified sampling (Cochran, Chapter 5).

The mean yearly catches per tow were also examined for evidence of step changes between 2001 and 2002. For this purpose a logarithmic transformation was carried out to stabilize the variance of the estimated averages and ordinary regression methods were used to account for time trends with up to quartic components. There were a four observed mean catches of zero, with two of these being in 2004. These were replaced by one half of the minimum non-zero catch for the species concerned in order to be able to use the logarithmic transformation. This resulted in a zero catch for splittail in 1977 being replaced by 0.00053 fish per tow, while zero catches for white sturgeon in 2001 and 2004 and a zero catch for white catfish in 2004 were all replaced by 0.00089 fish per tow.

A principal components analysis (Manly, 2005) was also conducted on the logarithms of estimated mean yearly catches. Principal components are linear combinations of the variables being considered, in this case the logarithms of yearly mean catches. The first principal component (PC1) is the linear combination of the variables that account for as much of the variation in the data as is possible. The second principal component (PC2) then accounts for as much as possible of the remaining variation, subject to the constraint that it is uncorrelated with PC1. The third principal component (PC3) then accounts for as much as possible of the remaining variation, subject to the constraint that it is uncorrelated with PC1 and PC2. The other principal components are defined in a similar way, with the last one accounting for all of the variation that is not accounted for by the other components, whilst being uncorrelated with all of these components.

The idea behind using a principal components analysis is that the principal components are indices representing changes in the whole community of fish, rather than just an individual species. For example, if one group of fish consistently increased in abundance over time while another group consistently decreased over time then this would be expected to be reflected in one of the principal components.

Once the principal components were obtained, their values were analyzed by ordinary regression methods to see whether they displayed significant time trends, or evidence of a step change 2001 and 2002. This was the same type of analysis as used on the yearly mean values.

This report makes no attempt to relate changes in measured fish abundance to values of environmental variables. The results of that type of analysis will be presented in a separate report.

The Data

The data used for the log-linear model analyses are provided in Appendix A. They are total fish counts by year and area, for each of ten species as obtained from FMWT fishing. A total of 110 sampling stations in 14 geographical areas were sampled, as indicated in Figure 1. The sampling stations were not always sampled every year, and in some years some of the geographical areas were not sampled. No sampling was carried out in 1974 and 1979.

For the other analyses summary data were used, consisting of the logarithm of the estimated mean catch per tow for the entire Sacramento-San Joaquin Delta, as shown in Appendix B.

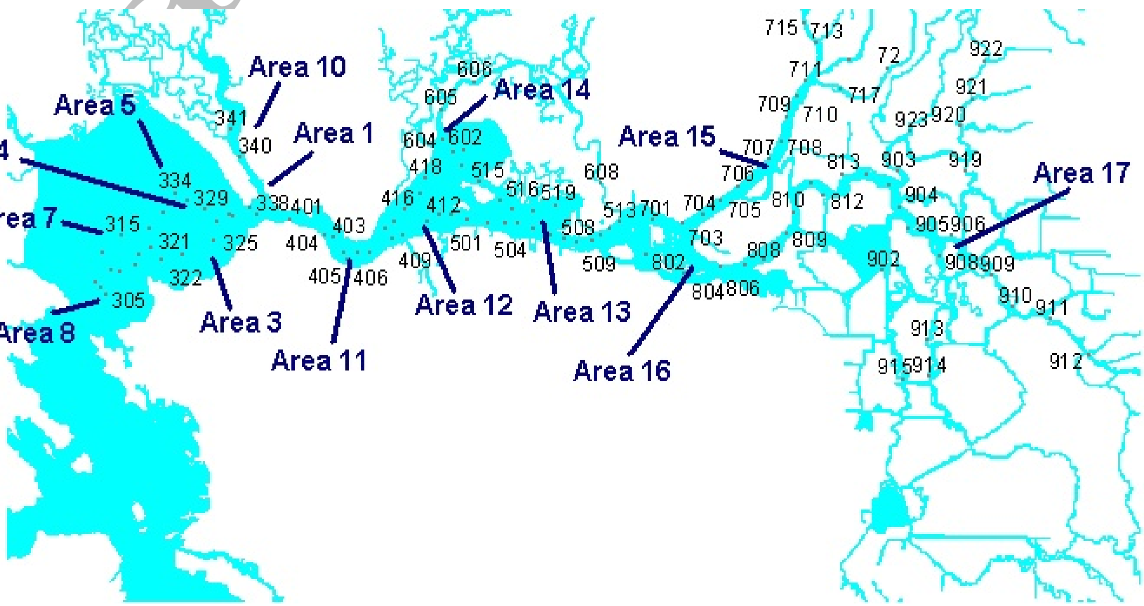

Figure 1 The sampled areas for fall midwater trawls in the Sacramento-San Joaquin Delta. Areas numbered 2, 6 and 9 were not sampled and are not shown in the figure.

Log-Linear Models on Counts

Log-linear models were estimated using GenStat (Lawes Agricultural Trust, 2005). As the catch is expected to be proportional to the number of trawls taken this was allowed for by using the logarithm of the number of trawls as an offset for fitted models.

As noted above, the most complicated model considered allows for a quartic time trend that varies from area to area. Hence in area i the expected number of fish of species j caught in year t takes the form

$$E(Y_{ij}) = \exp\{\log_e(N) + \alpha_{0ij} + \alpha_{1ij}t + \alpha_{2ij}t^2 + \alpha_{3ij}t^3 + \alpha_{4ij}t^4\}, \qquad (1)$$

where $\log_e(N)$ is the offset that takes into account the number of trawls made, and the α parameters are estimated. To reduce the correlation between the polynomial terms, t was set equal to the year minus 1985. Depending on the result of significance tests some of the powers of t were removed from the above equation. Also, in some cases the coefficients could be the same in all areas.

To allow for a possible step change an indicator variable, I_t, was added to equation (1). This was set equal to 1 for samples taken in 2002, 2003 and 2004, but was 0 in all other years. Thus the equation becomes

$$E(Y_i) = \exp\{\log_e(N) + \alpha_{0ij} + \alpha_{1ij}t + \alpha_{2ij}t^2 + \alpha_{3ij}t^3 + \alpha_{4ij}t^4 + \beta I_t\}, \qquad (2)$$

where β is the step change effect to be estimated. The step change effect on the expected number of fish caught is then exp(β), i.e, the expected number of fish after 2001 was the prediction from equation (1) multiplied by exp(β).

For all fitted models a heterogeneity factor was estimated. This allowed the variation in fish counts to be greater than what is expected on the assumption that the counts follow Poisson distributions. The variance of a count is still, however, assumed to be proportional to the expected value.

Serial correlation between the successive observations could have an effect on the fitting of the various models. This was examined by calculating the correlation between each standardized deviance residual and the following deviance residual. This was done separately for each of the areas sampled where more than ten fish were caught. The average of these correlations was then calculated to indicate the extent to which successive residuals are similar.

Regression Analysis on Logarithms of Mean Counts

The estimated mean counts per tow for the ten fish groups are shown in Appendix B, with their standard errors. For this purpose each of the 14 sampling areas (Figure 1) was treated as a separate strata and estimates were calculated assuming that the tows for each area were effectively equivalent to tows at random locations. The strata were also treated as being approximately of the same size. Equations (5.1) and (5.7) of Cochran (1977) were used for estimation.

If the variance of a sample mean $\bar{x}$ is $\mathrm{Var}(\bar{x})$, then it is a standard result that the variance of $\log_e(\bar{x})$ is approximately $\mathrm{Var}(\bar{x}) / \bar{x}^2$. This allows the logarithms of the yearly mean counts in Appendix B to be assigned approximate variances. This stabilizes the variance considerably for some fish groups. Also, as estimated variances are available it is possible to use the inverse of these variances as weighs for the regression of the logarithms of mean counts against variables accounting for trend and a step change between 2001 and 2002. Weighted regression was examined, but it was found that the variance of the residuals from the estimated equations was generally much larger than what is expected from sampling errors. Thus the unaccounted for variation seems mainly due to random variation from year to year in population sizes, rather than sampling errors. For this reason unweighted regression was used rather than weighted regression.

All of the regression calculations were done in GenStat. The first equation considered was

$$\log_e(Y_i) = \alpha_0 + \alpha_1 t_i + \alpha_2 t_i^2 + \alpha_3 t_i^3 + \alpha_4 t_i^4 + e_i, \qquad (3)$$

where Y_i denotes the mean annual count per tow for a particular fish in year i, t is the year minus 1986, e_i represents random variation about the quartic trend defined by the time variables, and the α values are parameters to be estimated. The quartic term t_i^4 was then removed if the estimated coefficient was not significant at the 5% level. Similarly the cubic, quadratic and linear terms were removed in that order if their coefficients were not significant.

Once an appropriate order of polynomial for the time trend was chosen, a step trend variable was added to the equation, in a similar way to what was done for equation (2). Thus a term βI_t was added to the right-hand side of the equation, where I_t is 0 for years 1967 to 2001 and 1 for 2002, 2003 and 2004. This step trend variable then estimates the size of the change between 2001 and 2002, assuming that one took place.

Durbin-Watson tests (Durbin and Watson, 1951) were carried out to examine whether the residuals from the regressions showed evidence of serial correlation. This test only applies for normally distributed data, and is therefore not suitable for use with the log-linear modeling.

Principal Components Analysis

GenStat was also used for the principal components analysis. The variables used for the analysis were the natural logarithms of mean yearly catches per tow for the ten fish groups (Appendix B), and the analysis was based on the correlation matrix for these variables.

The trend in each of the principal components was modeled using up to a quartic polynomial, as

$$PC = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3 + \alpha_4 t^4 + e, \qquad (3)$$

where the α values are parameters to be estimated, and e represents a random error term. The terms t^4, t^3, t^2 and t were removed in order if their estimated coefficients were not significant at the 5% level, in the same way as was done for the regression analyses described above.. The resulting equation was assumed to represent the underlying trend in the component reasonably well. At that point a step variable was introduced with the value 0 for years 1967 to 2001 and 1 for 2002 to 2004, to see if there was any evidence of a step change between the years 2001 and 2002. Durbin-Watson tests were used to see whether regression residuals display serial correlation.

Results for Log-linear Modeling

Figure 2 shows the observed mean numbers of fish caught per tow over all areas based on the stratified sampling estimation, together with the expected numbers from the model of equation (2), with insignificant trend terms removed if necessary. The estimated step change in 2002 is quite distinct in the fitted curve for delta smelt, threadfin shad, splittail, striped bass age 1, white sturgeon and chinook. In each of these cases the step change is a drop in numbers.

Table 1 gives a summary of the models chosen to represent the trends in catch numbers, the estimated step change parameter $\hat{\beta}$, and $\exp(\hat{\beta})$, which is the estimated effect on fish numbers. The estimated β parameter is significantly different from zero at the 5% level for everything except striped bass age 1, for which the parameter is close to being significant ($p = 0.066$). There are two positive estimates and eight negative estimates.

Serial correlation between the successive residuals from the fitted log-linear models does not appear to be an important issue. Over all species the mean estimated correlation between successive standardized residuals is -0.02, with the range for the individual species varying from -0.15 for delta smelt to 0.06 for threadfin shad.

Results for Linear Regressions on Logarithms of Counts

Figure 3 shows the estimated logarithms of the mean catch per tow with trend curves fitted using equation (3), with insignificant trend terms removed if necessary, and an allowance for possible step effects added in. The pattern is quite similar to that shown in Figure 2 for delta smelt, threadfin shad, longfin shad, striped bass age 1, white catfish, and chinook salmon, although Figure 2 is for the catch per unit effort (CPUE) while Figure 3 is for the natural logarithm of the CPUE.

Table 2 shows the estimated step parameters β for the regression equations, in the same format as Table 1 because the same step parameters are being estimated. The signs of the step changes are the same for all fish groups in Tables 1 and 2. However, in all cases the size of the change is estimated to be less with linear regression, and the results are far less significant, except for threadfin shad and striped bass age 0.

It is not surprising that the estimates of step effects are different for the log-linear models and the linear regression models because with the log-linear models there was much more data, at the level of the geographical areas, and in some cases different time trends were estimated for these areas. The larger data set for log-linear modeling also explains why the estimated step changes are more significant. In addition, there is some ambiguity in whether changes in abundance between 2001 and 2002 are considered as part of the trend or as a distinct step effect, and this will depend on the model that is assumed for trend.

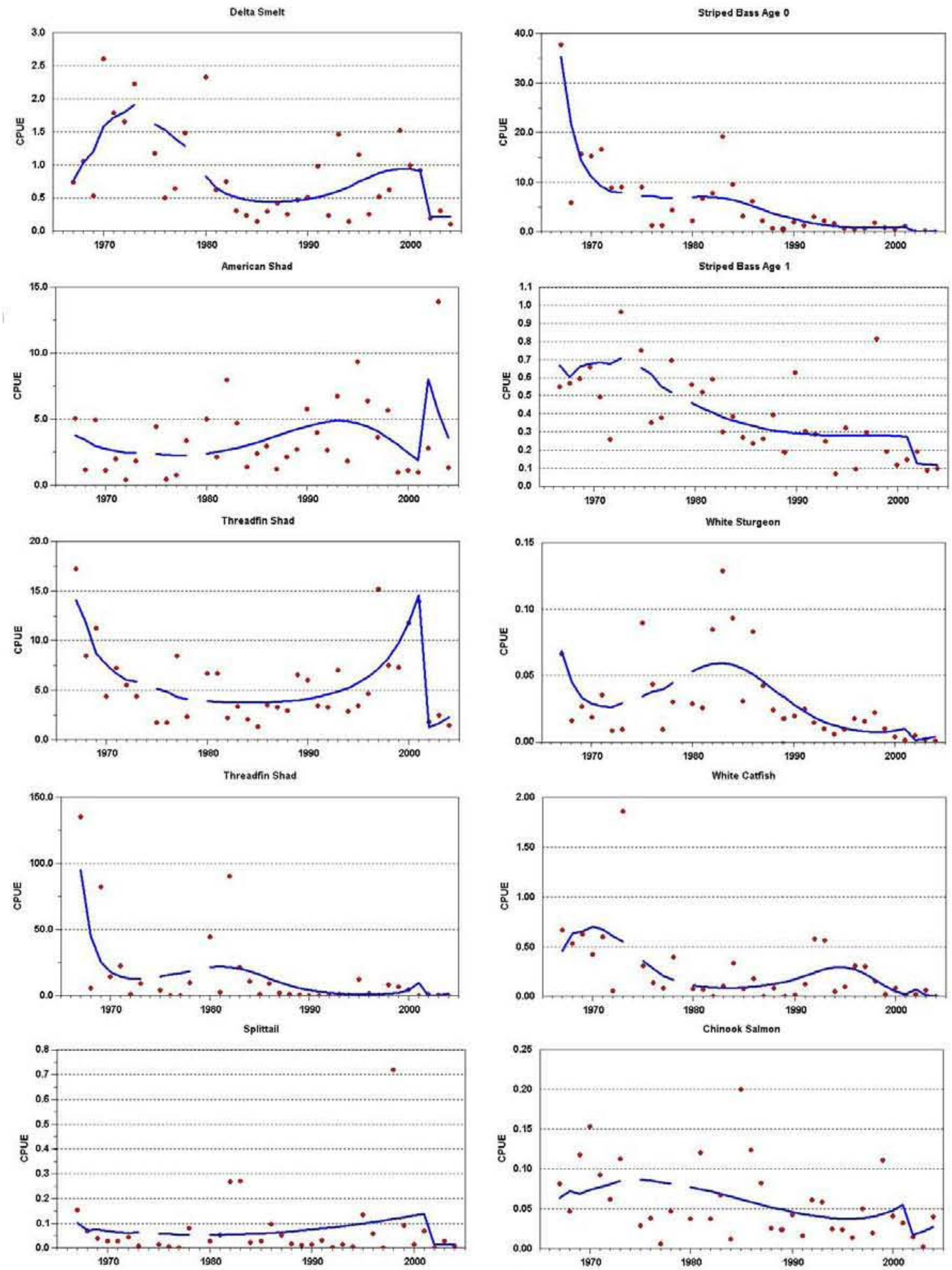

Figure 2 Observed and expected catch per unit effort (CPUE) for ten species of fish. The curves are the estimates based on log-linear models using equation (2).

Table 1 Summary of the estimation of the trend and step change effects using log-linear modeling.

Species	Trend Model	$\hat{\beta}$	SE($\hat{\beta}$)	exp($\hat{\beta}$)[1]	p-value
Delta Smelt	Quartic time trends varying with the area.	-1.384	0.439	0.251	0.002
American Shad	Quartic time trends with linear coefficient varying with the area.	1.741	0.274	5.703	< 0.001
Threadfin Shad	Quartic time trend, the same in all areas.	-2.686	0.240	0.068	< 0.001
Longfin Smelt	Quartic time trend, the same in all areas.	-5.840	1.040	0.003	< 0.001
Splittail	Cubic time trend, the same in all areas.	-2.272	0.533	0.103	< 0.001
Striped Bass Age 0	Quartic time trend, with linear and quadratic components varying with the area.	-3.001	0.938	0.050	0.001
Striped Bass Age 1	Quartic time trends, with linear components varying with the area.	-0.762	0.414	0.467	0.066
White Sturgeon	Quartic time trend, the same in all areas.	-2.211	0.840	0.110	0.009
White Catfish	Quartic time trend, the same in all areas.	2.271	0.821	9.689	0.006
Chinook Salmon	Cubic time trends, with linear and quadratic coefficients varying with the area.	-1.308	0.445	0.270	0.003

[1]exp($\hat{\beta}$) is the estimated step effect on numbers. For example for delta smelt it is estimated that the step effect was to multiply numbers by 0.251, i.e., there was a 74.9% reduction in numbers.

It is not obvious why the estimated effects are lower with linear regression, but these estimates would seem to be a better indication of the overall changes in the system as the data in this case are estimates of the average catch per tow that would be obtained for samples taken over the whole delta. It is interesting to note that the estimates by log-linear modeling and linear regression are very similar for delta smelt and white catfish, and fairly similar for threadfin shad, splittail and chinook salmon.

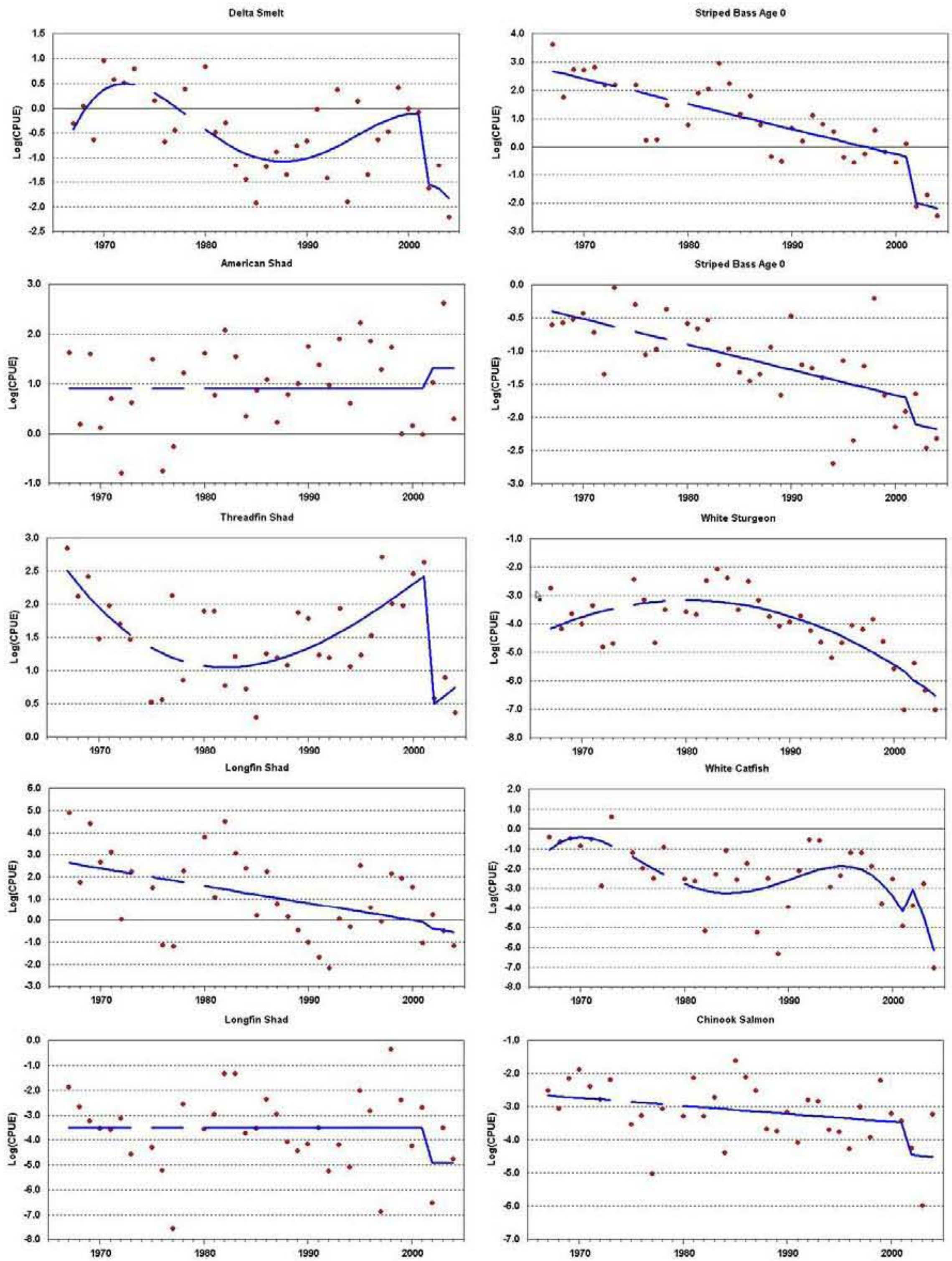

Figure 3 Estimated logarithms of mean catches per tow for the whole Delta (points) and fitted regression equations (curves).

Table 2 Summary of the estimation of the trend and step change effects using regression modeling of the logarithms of estimated mean catches per tow over the Delta.

Species	Trend Model	$\hat{\beta}$	SE($\hat{\beta}$)	exp($\hat{\beta}$)[1]	p-value
Delta Smelt	Quartic time trend.	-1.370	0.858	0.254	0.121
American Shad	No trend.	0.410	0.500	1.506	0.419
Threadfin Shad	Cubic time trend.	-2.043	0.526	0.130	< 0.001
Longfin Smelt	Linear time trend.	-0.223	1.131	0.800	0.845
Splittail	No trend.	-1.417	0.899	0.242	0.125
Striped Bass Age 0	Linear trend.	-1.577	0.509	0.207	0.004[2]
Striped Bass Age 1	Linear trend.	-0.364	0.337	0.695	0.288
White Sturgeon	Quadratic trend.	-0.075	0.639	0.928	0.907
White Catfish	Quartic trend.	2.227	1.851	9.272	0.238
Chinook Salmon	Linear trend.	-0.959	0.556	0.383	0.094

[1]exp($\hat{\beta}$) is the estimated step effect on numbers. For example for delta smelt it is estimated that the step effect was to multiply numbers by 0.251, i.e., there was a 74.9% reduction in numbers.
[2]This p-value may be too low because of serial correlation (see text).

The result of Durbin-Watson tests on the regression residuals was not significant at the 5% level for American shad, threadfin shad, splittail, striped bass age 0, white catfish, and chinook salmon. The result was in the indeterminate area for delta smelt, longfin smelt, and white sturgeon. For striped bass age 0 the result was significant at the 5% level, in the direction of indicating positive correlation between the regression residuals. Over all, therefore, there was not strong evidence of serial correlation, except for striped bass age 0. No allowance was made for the serial correlation with striped bass age 0, although it should be noted that the significance level of the step effect may be exaggerated to some extent for this fish.

Results for Principal Components Analysis

Table 3 shows the Pearson correlations between the logarithms of the CPUE variables shown in Appendix B. There are 45 correlation distinct coefficients altogether, or which 19 (42%) are significantly different from zero at the 5% level. All of the significant correlations are positive, and involve all fish groups except American shad. The highest correlation is 0.68, between white sturgeon and striped bass aged 0. The presence of high correlations indicates that a principal components analysis based on the correlation matrix is worthwhile.

Table 3 Correlations between logarithms of the estimated catch per tow for the whole Sacramento-San Joaquin delta, with abbreviate fish names on columns. Values that are significantly different from zero at the 5% level are underlined.

	DSm	AmShd	ThShd	LfSm	Splittl	StrBs0	StrBs1	WhiSt	WhiCf	Chink
Delta Smelt	1.00	-0.08	0.45	0.39	0.22	0.40	0.53	0.08	0.35	0.26
American Shad	-0.08	1.00	-0.04	0.29	0.32	-0.03	0.09	0.19	0.13	-0.24
Threadfin Shad	0.45	-0.04	1.00	0.20	0.07	0.20	0.12	-0.13	0.21	0.17
Longfin Smelt	0.39	0.29	0.20	1.00	0.58	0.61	0.50	0.51	0.33	0.36
Splittail	0.22	0.32	0.07	0.58	1.00	0.40	0.22	0.32	0.01	0.24
Striped Bass 0	0.40	-0.03	0.20	0.61	0.40	1.00	0.65	0.68	0.55	0.56
Striped Bass 1	0.53	0.09	0.12	0.50	0.22	0.65	1.00	0.59	0.45	0.35
White Sturgeon	0.08	0.19	-0.13	0.51	0.32	0.68	0.59	1.00	0.36	0.31
White Catfish	0.35	0.13	0.21	0.33	0.01	0.55	0.45	0.36	1.00	0.19
Chinook Salmon	0.26	-0.24	0.17	0.36	0.24	0.56	0.35	0.31	0.19	1.00

The coefficients for the principal components PC1 to PC10 based on the correlation matrix are shown in Table 4, while the values of the components for the sampled years (the component scores) are shown in Table 5. In order, these components account for 39.5%, 15.4%, 12.3%, 10.6%, 6.4%, 4.5%, 4.3%, 3.3%, 2.1% and 1.6% of the variation in the data. Between them, PC1 to PC3 account for 67.3% of the total variation, and show evidence of time trends over the period from 1967 to 2004 and a step change between 2001 and 2003. These components are therefore discussed further below. The components PC5 and PC9 show evidence of trends, but no step change between 2001 and 2002, while the other components show no evidence of either time trends or a step change. Therefore the components PC4 to PC10 are not considered further.

PC1 is a linear combination of the standardized (to a mean of zero and a standard deviation of one) logarithms of average fish count variables that has a positive coefficient for every fish. This therefore has the clear interpretation of being an index of overall fish abundance. It accounts for 39.5% of the total variation in the data, and in this sense is the most important index of changes in the fish community.

PC2 has large positive coefficients (> 0.30) delta smelt and threadfin shad, and large negative coefficients (< -0.30) for American shad, splittail and white sturgeon. It can therefore be interpreted as an index of the relative abundance of delta smelt and threadfin shad compared to American shad, splittail and white sturgeon. This index accounts for 15.4% of the variation in the data.

For PC3 the high positive coefficients are for white sturgeon and chinook salmon, with high negative coefficients for delta smelt, American shad and threadfin shad. This is therefore an index of white sturgeon and chinook abundance compared to delta smelt, American shad and threadfin shad..

Table 4 The principal components based on standardized logarithms of mean catches per tow for the whole delta region. The rows give the coefficients of the logarithms of means for each of the fish groups. For example, PC1 = 0.293 $\log_e$(Delta Smelt) + 0.078 $\log_e$(American Shad) + ... 0.288 $\log_e$(Chinook Salmon).

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Delta Smelt	0.293	0.396	-0.325	0.052	-0.554	0.241	0.087	-0.015	-0.523	0.048
American Shad	0.078	-0.556	-0.463	0.275	0.158	-0.087	0.521	-0.116	-0.159	0.228
Threadfin Shad	0.147	0.464	-0.525	-0.032	0.403	-0.521	-0.141	-0.120	0.058	-0.122
Longfin Smelt	0.398	-0.188	-0.195	-0.178	0.029	0.035	-0.090	0.841	0.125	-0.065
Splittail	0.265	-0.339	-0.296	-0.511	-0.063	0.306	-0.280	-0.461	0.179	-0.213
Striped Bass 0	0.448	0.041	0.210	-0.019	0.162	-0.011	-0.255	-0.130	0.008	0.803
Striped Bass 1	0.398	0.041	0.120	0.235	-0.471	-0.296	0.258	-0.143	0.603	-0.106
White Sturgeon	0.355	-0.315	0.351	0.111	0.005	-0.426	-0.231	-0.091	-0.517	-0.360
White Catfish	0.300	0.117	0.031	0.598	0.385	0.537	-0.098	-0.065	0.097	-0.280
Chinook Salmon	0.288	0.228	0.310	-0.451	0.324	0.104	0.648	-0.050	-0.100	-0.129
Variance[1]	3.95	1.54	1.23	1.06	0.64	0.45	0.43	0.33	0.21	0.16
%	39.5	15.4	12.3	10.6	6.4	4.5	4.3	3.3	2.1	1.6
Cumulative %	39.5	55.0	67.3	77.9	84.2	88.7	93.0	96.3	98.4	100.0

[1]The variance of the principal component when evaluated for each of the years where sampling took place. The total variance is 10.0, and the % and cumulative % give the variance as a percentage of the total, and the sum of percentages for the components up to and including the one being considered.

When equation (3) was estimated for the PC1 values a cubic trend was found to be significant. When a step effect was added the step parameter was estimated as -2.579 with a standard error of 1.320. This is nearly significantly different from zero at the 5% level ($t = -1.95$, $p = 0.060$), implying a general drop in species abundances in the community between 2001 and 2002.

For PC2 a quartic trend was found to be significant. When a step effect was added to the regression equation the parameter was estimated to be -2.809 with standard error 1.373. This is just significantly different from zero ($t = -2.05$, $p = 0.049$), indicating a drop in delta smelt and threadfin shad abundance relative to American shad, splittail and white sturgeon abundance between 2001 and 2002.

For PC3 a quadratic trend was found to be significant. When a step effect was added to the equation the parameter was estimated to be 1.812 with a standard error of 0.776. This is significantly different from zero ($t = 2.33$, $p = 0.027$), indicating an increase in white sturgeon and chinook salmon abundance relative to delta smelt, American shad and threadfin shad abundance between 2001 and 2002.

Table 5 Values of the ten principal components (PC1 to PC10) for the sampled years 1967 to 2004.

Year	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
1967	3.65	-0.19	-1.06	-0.16	1.38	-0.68	-0.50	0.29	0.28	0.21
1968	1.50	1.14	-0.23	0.07	-0.04	0.28	-0.68	-0.27	0.67	-0.31
1969	2.71	0.05	-0.54	0.08	1.34	-0.40	0.45	0.67	0.67	0.20
1970	2.47	1.54	0.63	-0.27	-0.60	0.82	0.33	0.33	-0.06	0.26
1971	2.53	0.99	0.01	0.19	0.17	0.22	-0.09	0.40	-0.33	0.22
1972	0.22	2.05	0.52	-1.11	-0.59	0.63	-0.91	-0.48	-0.20	0.50
1973	2.19	1.62	0.36	1.00	-0.48	1.01	0.90	0.36	0.54	0.21
1975	1.54	-0.95	0.99	1.46	-1.15	0.08	0.18	0.01	-0.48	0.41
1976	-0.98	0.76	2.45	0.50	-0.79	0.22	-0.60	-0.17	-0.25	-0.71
1977	-1.97	2.05	0.33	1.99	-0.62	-1.27	-1.04	0.38	0.24	0.28
1978	1.75	-0.52	0.12	0.44	-1.04	0.86	0.23	-0.06	0.08	-0.16
1980	1.61	0.03	-1.29	0.24	-0.94	-0.42	0.42	0.87	-0.45	-0.16
1981	1.21	0.46	0.36	-0.72	0.25	-0.46	0.39	-0.54	0.28	0.05
1982	1.86	-2.56	-0.30	-1.23	-1.32	-0.70	0.11	0.55	-0.17	0.55
1983	1.97	-1.97	0.52	-0.86	0.79	-0.16	-0.58	-0.19	-0.27	0.26
1984	0.60	-1.27	1.52	0.92	-0.04	-0.06	-1.77	0.57	0.37	0.08
1985	-0.28	-1.14	2.29	-0.84	0.87	0.50	0.98	-0.30	0.17	-0.04
1986	1.24	-1.07	0.93	-0.81	1.15	0.13	-0.05	-0.05	-0.40	-0.34
1987	-0.36	-0.29	1.09	-1.74	-0.36	-0.70	-0.11	-0.14	-0.39	-0.16
1988	-0.99	-0.61	0.73	0.47	-0.19	-0.31	-0.08	-0.11	0.50	-0.64
1989	-2.04	-0.05	-0.44	-0.84	-0.45	-1.60	0.04	-0.13	-0.64	0.14
1990	-0.33	-0.20	-0.17	0.32	-0.41	-1.32	1.02	-1.04	0.23	0.30
1991	-0.78	-0.32	-0.26	0.97	-0.73	0.14	-0.13	-1.25	-0.65	-0.11
1992	-0.95	0.29	1.36	1.19	1.08	0.27	0.57	-1.01	0.17	0.20
1993	0.27	0.63	-1.06	0.94	0.56	0.57	0.94	-0.51	-0.73	0.19
1994	-2.74	-0.24	0.66	-0.13	1.35	0.49	-0.57	0.43	-0.24	0.72
1995	0.16	-1.27	-1.77	0.04	-0.71	0.75	0.50	0.19	-0.06	-0.26
1996	-1.43	-1.43	-1.05	0.57	1.25	0.55	-0.68	-0.21	-0.47	-0.52
1997	-0.71	1.47	-0.43	1.52	1.23	-1.21	0.88	0.27	-0.32	-0.41
1998	1.40	-1.18	-1.63	-0.09	-0.51	-0.21	-0.43	-0.91	1.17	-0.71
1999	0.02	1.27	-0.60	-1.96	-0.25	0.36	0.01	0.28	-0.55	-0.75
2000	-1.19	1.78	-1.23	-0.62	0.61	0.31	-0.40	0.76	-0.36	-0.44
2001	-2.06	2.08	-1.67	-1.74	-0.08	0.09	-0.49	-0.77	0.48	0.54
2002	-3.44	-0.61	0.45	0.80	-0.36	-0.12	0.64	1.23	0.35	-0.23
2003	-3.67	-1.98	-2.30	1.28	-0.08	1.03	-0.39	-0.03	0.04	0.49
2004	-4.95	-0.35	0.69	-1.88	-0.26	0.31	0.91	0.58	0.79	0.15
Mean	0.00	-0.00	-0.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00	0.00
Var	3.95	1.54	1.23	1.06	0.64	0.45	0.43	0.33	0.21	0.16

There is little evidence of serial correlation in the residuals for the three regressions. For PC1 the Durbin-Watson test is in the uncertain region, although suggesting positive correlation from one residual to the next. For PC2 and PC3 the test is definitely not significant at the 5% level.

Figure 4 shows the values of these three principal components, with the fitted regression line. For PC1 (overall fish abundance) there is a picture of decline from 1967 to 2000, with a large drop after 2001 to lower levels than ever recorded before that. For PC2 (delta smelt and threadfin shad abundance relative to American shad, splittail and white sturgeon abundance) the trend shows an increase up to about 1972, followed by a decrease up to about 1985, and then an increase up to 2001, at which point the step change (a drop) occurs. For PC3 (white sturgeon and chinook salmon relative to delta smelt, American shad and threadfin shad) the trend shows an increase up to 1982 followed by a decrease until the step change (upwards) in 2001.

For PC1 and PC2 the step change is apparent in the values of the components themselves as well as the fitted regression curves. There does therefore see to have been some abrupt change in the indices. However, with PC3 the values of the component are quite variable for 2002, 2003 and 2004, with two high values and one low value. Therefore in this case it is not really clear that there was a step change that persisted after 2002.

Conclusion

The data on fish abundance are consistent with stepwise changes in the observed numbers of fish caught in the FMWT between 2001 and 2002, with most changes being downwards. Based on log-linear models, the reductions are significant and very considerable for most of the species. Based on linear regression analyses of the logarithms estimated mean fish counts per tow the reductions are not so substantial and only two changes are significant at the 5% level. The evidence for step changes is therefore not so clear in this case, although the lack of significance must be due in part to the small amount of data for the regression analysis compared to the log-linear model analysis.

The results of a principal components analysis show that most of the variation (40%) in the fish community is related to the first component which is an index of the the overall abundance of species. In this respect there was a general downward trend in abundances from 1967 to 2001, with apparently a sharp drop at that point to a substantially lower level never recorded before. The stepwise change is not quite significant at the 5% level but nevertheless seems real.

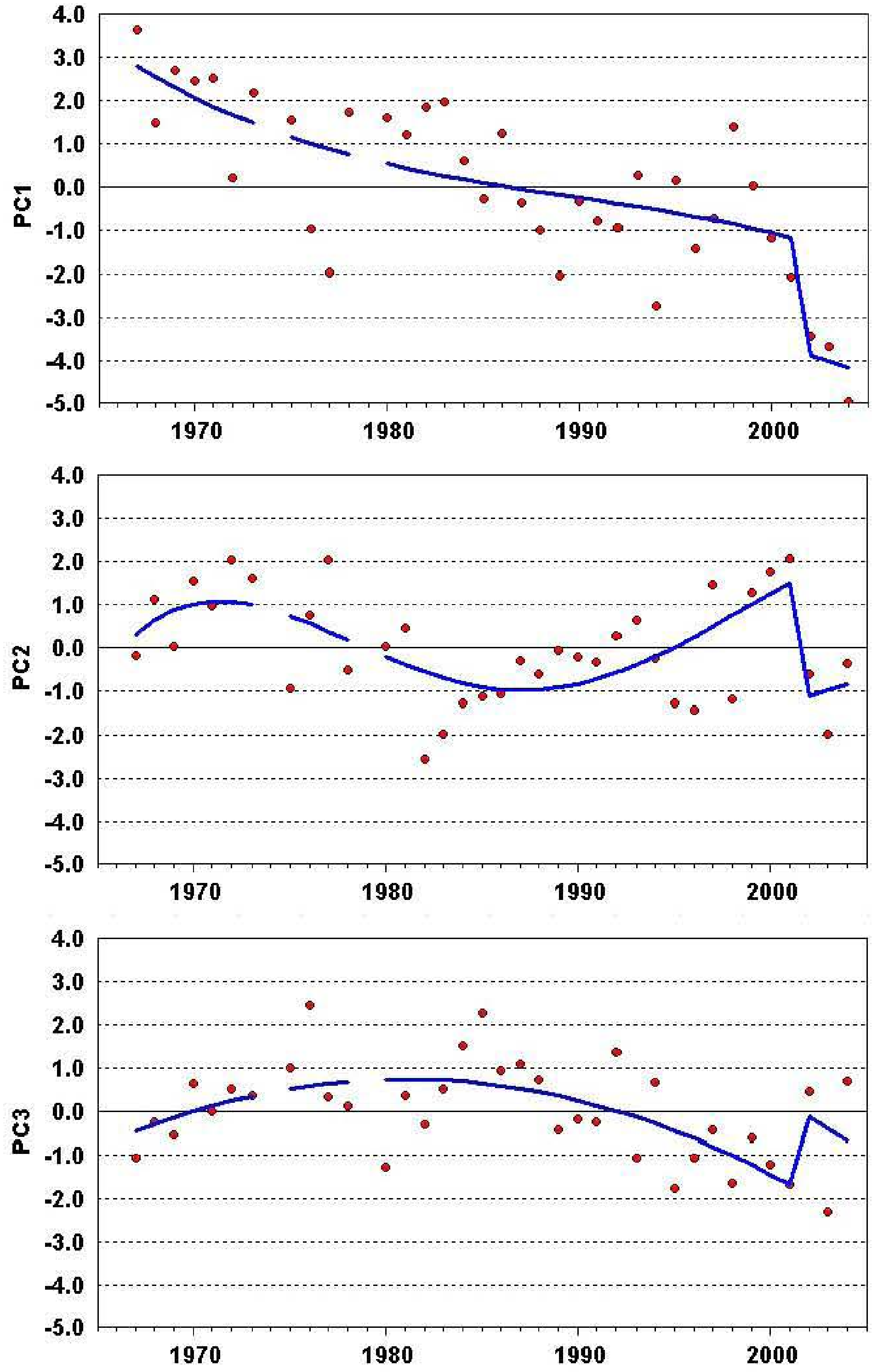

Figure 4 Principal component values (points) and fitted regression curves for components PC1 to PC3.

The second component accounts for 15% of the variation in the data, and is a contrast between the abundance of delta smelt and threadfin shad on one hand, and American shad, splittail and white sturgeon on the other hand. This component shows a sharp drop in 2001 which is significant ($p = 0.049$) and appears meaningful. Apparently, therefore, the general drop in fish numbers affected delta smelt and threadfin shad abundance more than the abundance of American shad, splittail and white sturgeon.

The third principal component accounts for 12% of the variation in the data, and also represents a contrast between the abundance of one group of species and the abundance of a second group. This component shows a significant step change upwards in 2001, but then in 2002 the component has a low value. The step change pattern is therefore not so clear in this case.

If a step change is indicated by a considerable change that seems to be maintained for at least three years then it can perhaps be argued that this occurred for PC1 between 1977 and 1978, and for PC2 between 1981 and 1982 (Figure 4). These apparent step changes can, however, also be accounted for by the previous one or two observations just having a large deviation from the underlying trend line.

References

Cochran, W.G. (1977). *Sampling Techniques*, 3rd Edit. Wiley, New York.

Durbin, J. and Watson, G.S. (1951). Testing for serial correlation in least squares regression. *Biometrika* 38: 159-78.

Lawes Agricultural Trust (2005). *GenStat 8th Edition*. VSN International Ltd., www.vsn-intl.com

Manly, B.F.J. (2005). *Multivariate Statistical Methods: a Primer*, 3rd Edit. Chapman and Hall/CRC, Boca Raton.

McCullagh, P. and Nelder, J.A. (1989). *Generalized Linear Models*. Chapman and Hall, London.

Analyses B: Log-Linear Modeling, Linear Regression, and Principal Components Analysis for Midwater Trawl and Otter Trawl Fish Counts 1980-2004 from the Bay Study

Bryan F.J. Manly
Western EcoSystems Technology Inc.
bmanly@west-inc.com

Contents

Summary 2

Introduction 5

The Data 6

Log-Linear Models 7

Regression Analysis on Logarithms of CPUE 8

Principal Components Analysis 8

Results 9
- Log-Linear Modeling of Midwater Trawl Counts 9
- Regression Analyses with CPUE for Midwater Trawl Counts 10
- Principal Components Analysis for Midwater Trawl Counts 12
- Log-Linear Modeling of Otter Trawl Counts 16
- Regression Analyses with CPUE for Otter Trawl Counts 16
- Principal Components Analysis for Otter Trawl Counts 22

Discussion 26

Conclusion 30

References 31

Appendix A: Fall Midwater Trawl Data Used for Log-linear Modeling 32

Appendix B: Otter Trawl Data Used for Log-linear Modeling 43

Summary

- Analyses conducted on the Fall Midwater Trawl data have been repeated on the midwater trawl and otter trawl data from the Bay Study. These analyses consisted of log-linear modeling on the counts of fish in nets, linear regression modeling of the logarithms of mean annual catch per unit effort (CPUE) values (i.e. the mean annual fish counts per trawl, and principal components analysis.

- For the Bay Study there are seven sampling areas and samples taken throughout the year. There are counts for six fish types with the midwater trawl and 21 fish types with the otter trawl. For the midwater trawl the fish are American shad age 0, chinook salmon age 0, delta smelt age 0, longfin smelt age 0, striped bass age 0, and threadfin shad. For the otter trawl the fish are bigscale log perch, channel catfish, common carp, green sturgeon, longfin smelt, Pacific lamprey, Pacific staghorn skulpin, prickly sculpin, redear sunfish, river lamprey, shimofuri gobi, shokinhaze gobi, splittail age 0, starry flounder age 0 and age 1 (separately), striped bass age 0, threespine stickleback, tule perch, white catfish, white sturgeon, and yellow gobi age 0.

- Monthly counts could be used for the log-linear model analyses but this would result in a very large number of zero observed counts. Quarterly data were used to reduce this problem. For the midwater trawl data for all six fish types could be analyzed. For the otter trawl there was too little data for many of the 21 fish types and only the counts for channel catfish, longfin smelt, Pacific staghorn skulpin, shimofuri gobi, starry flounder age 0 and age 1 (separately), white catfish, and yellow gobi age 0 were therefore considered.

- For the analysis of logarithms of yearly CPUE only samples for geographical areas 1 to 5 were used because there was no sampling in areas 6 and 7 before 1991. Principal components analysis was also carried out using the same logarithms of yearly CPUE values from areas 1 to 5 only. For these analyses the CPUE values for channel catfish, longfin smelt, Pacific staghorn skulpin, river lamprey, starry flounder age 0 and age 1 (separately), striped bass age 0, threespine stickleback, tule perch, white catfish, white sturgeon, and yellow gobi age 0 were used.

- For the log-linear model analyses the models considered allowed for quarterly seasonal effects, geographical area effects, and up to quartic time trends that could vary with the geographical area. If possible, because of non-significant effects, the time trends were simplified to cubic, quadratic, or linear functions, not necessarily varying with the area. Having estimated a model for the quarterly seasonal effects, area effects and time trends, a step effect was added to the model for 2001 to 2002, so that the mean could have a step change at that time.

- The regression analyses on logarithms of annual CPUE consisted on choosing a trend model with up to quartic terms for time and then adding a step effect between 2001 and 2002.

- Principal components analyses were carried out using the correlation matrix for the logarithms of mean annual CPUE, and these were regarded as indicators of community changes. The values for the principal components were analyzed using linear regression in the same manner as the logarithms of annual CPUE to estimate step effects between 2001 and 2002.

- For the log-linear modeling of midwater trawl quarterly counts there are significant step effects between 2001 and 2002 for American shad (increase), chinook salmon (decrease), and threadfin shad (decrease). Plots of observed versus expected counts show that only threadfin shad seems to have an obvious step change.

- The regression analyses on the logarithms of annual CPUE from midwater trawls in areas 1 to 5 show no evidence of any step effects between 2001 and 2002. Similarly, the principal components based on these data show no evidence of step effects.

- For the log-linear modeling of otter trawl quarterly counts there are significant step effects between 2001 and 2002 for longfin smelt age 0 (increase), Pacific staghorn skulpin age 0 (increase), starry flounder age 0 (increase), striped bass age 0 (decrease), and yellow gobi age 0 (decrease). However, plots of observed versus expected counts do not display any obvious step effects.

- The regression analyses on the logarithms of annual CPUE from otter trawls in areas 1 to 5 show no evidence of any step effects between 2001 and 2002. Similarly, the principal components based on these data show no evidence of step effects.

- Although there appear to have been clear changes in the abundances of some species over the period from 1980 to 2004, the analyses have given only limited evidence of step changes between 2001 and 2002, from the log-linear modeling analyses only. However, in general the estimates of step effects that are significantly different from zero are consistent in direction.

- The log-linear model analyses were carried out on data from areas 1 to 7 but the regression analyses were carried out on the data from areas 1 to 5 only because areas 6 and 7 were not sampled before 1991. This does not seem to explain some differences between estimated step effects from the two types of analysis.

- The log-linear model and regression analyses are based on the assumption that step changes in fish numbers may have occurred between 2001 and 2002. It is suggested that a better but more complicated analysis is possible which considers that a step change may have occurred but does not specify when. This is called the change point problem which recognizes the fact that if a time series is observed, there appears to be a change in mean between times t_{i-1} and t_i, and a test is made for a change at that point only, then there may be a high probability of obtaining a significant result even when the series actually has no changes in the mean at any time.

- A preliminary analysis of this type has been conducted based on the log-linear model for threadfin shad from the Bay Study midwater trawl, for which the estimated step effect between 2001 and 2002 is very highly significant. Data were simulated using as a null model the estimated log linear model for this fish with effects for the sampling area and quarters of the year, and quartic time trends varying with the sampling areas, with no step changes. Based on the model, 1,000 new sets of data were generated using bootstrap resampling of residuals, to compare with the original data. This analysis shows that a step change between 2001 and 2002 is not the most significant out of step changes for all possible times. Overall the observed data are not consistent with the null model, with the largest of the possible estimated step changes (an increase between 2000 and 2001) having a probability of only about 0.02 of occurring with the null model. The probability of the estimated change between 2001 and 2002 occurring with the null model is much larger at about 0.13.

- The simulation demonstrates that the asymptotic theory usually used to interpret the results from log-linear models is not very effective with the threadfin shad data, presumably because of the large number of zero and small observed counts. The significance levels estimated in the usual way can apparently be much more significant than they should be. This indicates that the significance levels for estimated effects with log-linear modeling presented in this report and an earlier one should be regarded with caution for the present.

- It is concluded that the evidence for a step change in fish numbers between 2001 and 2002 is not as clear from the Bay Study data as it was from the Fall Midwater Trawl data. In particular, for the Bay Study all of the evidence for step changes comes from log-linear model analyses but the preliminary simulation study reported here suggests that standard methods for assessing the significance of these step effects may not be reliable for data of the type being considered.

Introduction

The analyses described here are similar are similar to those labeled as Analyses A (Manly, 2005a). The earlier analyses were on fish counts from the fall midwater trawl (FMWT) over the Sacramento-San Joaquin Delta from 1967 to 2004. For that analysis counts were available for ten fish types (American shad, chinook salmon, delta smelt, longfin smelt, splittail, striped bass age 0, striped bass age 1, threadfin shad, white catfish, and white sturgeon). Log-linear models were fitted to the counts for individual fish types, allowing for differences between the catches in 14 different geographical areas, time trends, and a step change between 2001 and 2002. The mean annual catch per tow (catch per unit effort, CPUE) was also estimated for the whole of the Sacramento-San Joaquin Delta, treating the data as coming from stratified sampling of the 14 geographical areas. Logarithms of these CPUE values were then analyzed by multiple linear regression for trend and a step effect between 2001 and 2002. A principal component analysis was also carried out on the logarithms of the CPUE in order to examine changes over time in the community structure.

The log-linear model analyses showed that all ten fish types displayed trends in abundance from 1967 to 2004, with the trends varying significantly between sampling areas in some cases. The step change parameter was significant at the 5% level for all fish types except striped bass age 1, for which the parameter was nearly significant ($p = 0.066$). There were eight negative parameter estimates implying a drop in numbers, and two positive estimates indicating an increase. For the fish with a decrease the estimated drop in numbers ranged from a loss of 99.7% of the fish for longfin smelt to a loss of 53% of the fish for striped bass age 1. The two fish with an estimated increase in numbers were American shad (up 470%) and white catfish (up 869%).

The regression analyses of logarithms of CPUE showed significant time trends for all of the fish groups except American shad and splittail. Estimated step changes between 2001 and 2002 were in the same directions as those estimated from log-linear models, but only two of these estimated changes are significant at the 5% level. Furthermore, the sizes of the estimated changes are less with the regression analyses than with the log-linear models.

Three principal components account for 67.3% of the variation in the logarithms of FMWT annual estimated mean catches. These all display significant trends with time and significant step changes between 2001 and 2002. The first principal component (PC1) represents general fish abundance. This shows a steady decline from 1967 to 2001and then a substantial drop. PC2 represents a comparison of abundances of two groups of fish. It shows varying trends with time with a substantial drop between 2001 and 2002. PC3 also represents a comparison of abundances between two groups of fish. There is some trend before 2001 with an apparent increase at that time, although the value in 2003 was low so that this was not a consistent change.

The analyses just described have been repeated on the data from the Bay Study. Here the data have a more complicated structure because fish counts are available from both midwater trawls and otter trawls, for seven geographical areas, in different months through the year. With the midwater trawls there are counts available for six fish species, while for the otter trawl there are counts for 20 fish species, with two age classes for one of these. Some of the otter trawl species have very low numbers.

The Data

The sampling area for the Bay Study is shown in Figure 1. Appendix A shows the data used for log-linear modeling for the midwater trawl data. These are numbers of fish captured in each quarter of the year, in each of the seven geographical areas, in each year, 1980 to 2004. The six species of fish considered are American shad age 0, chinook salmon age 0, delta smelt age 0, longfin smelt age 0, striped bass age 0, and threadfin shad.

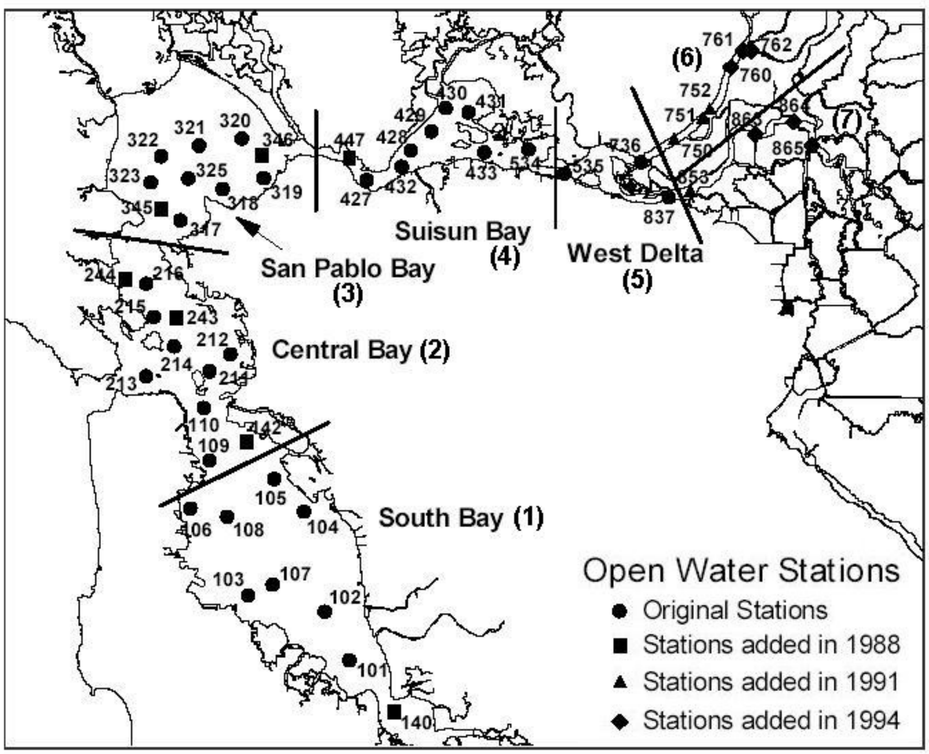

Figure 1 Sampling stations for the Bay Study divided into seven geographical areas (South Bay, Central Bay, etc.). Sampling began in 1980.

Appendix B gives similar data but from the otter trawls. In this case the 21 fish considered are bigscale log perch, channel catfish, common carp, green sturgeon, longfin smelt, Pacific lamprey, Pacific staghorn skulpin, prickly sculpin, redear sunfish, river lamprey, shimofuri gobi, shokinhaze gobi, splittail age 0, starry flounder age 0 and age 1 (separately), striped bass age 0, threespine stickleback, tule perch, white catfish, white sturgeon, and yellow gobi age 0.

Monthly counts could be used for the log-linear model analyses but this would result in a very large number of zero observed counts. Quarterly data were used to reduce this problem, but still there was too little data for many of the 21 fish types. Only the counts for channel catfish, longfin smelt, Pacific staghorn skulpin, shimofuri gobi, starry flounder age 0 and age 1 (separately), white catfish, and yellow gobi age 0 were therefore analyzed.

For the analysis of logarithms of CPUE an attempt was made to use quarterly average catch rates. However, a large number of these are zero so yearly CPUE values were used instead. The CPUE values were only calculated for the samples from the areas 1 to 5 shown in Figure 1 because there was no sampling in areas 6 and 7 before 1991. Principal components analysis was also carried out using the same logarithms of yearly CPUE values from areas 1 to 5 only. For these analyses the CPUE values for channel catfish, longfin smelt, Pacific staghorn skulpin, river lamprey, starry flounder age 0 and age 1 (separately), striped bass age 0, threespine stickleback, tule perch, white catfish, white sturgeon, and yellow gobi age 0 were used.

Log-Linear Models

The log-linear model analyses were similar to those described by Manly (2005) but there was an extra factor for the sampling quarter within years. For one type of fish count what was done was to first fit a model allowing for differences between counts in different quarters of the year and quartic time trends. The expected count for the fish in area i in month j of year t then took the form

$$E(Y) = \exp\{\log_e(N) + \alpha_{0ij} + \alpha_{1ij}t + \alpha_{2ij}t^2 + \alpha_{3ij}t^3 + \alpha_{4ij}t^4 + q_j\}, \qquad (1)$$

where $\log_e(N)$ is the offset that takes into account the number of trawls made, and the α parameters are estimated, as are the quarter effects q_j. To reduce the correlation between the polynomial terms, t was set equal to the year minus 1992. Depending on the result of significance tests some of the powers of t were removed from the above equation. Also, in some cases the α coefficients could be made the same in all areas. Quarter effects were assumed to always exist. Model fitting was carried out using GenStat (Lawes Agricultural Trust, 2005)

Once a model for area, quarter and trend effects was determined, a step effect was added for observations after 2001. This was done by modifying equation (1) or a simpler version of this equation to

$$E(Y) = \exp\{\log_e(N) + \alpha_{0ij} + \alpha_{1ij}t + \alpha_{2ij}t^2 + \alpha_{3ij}t^3 + \alpha_{4ij}t^4 + q_j + \beta I_t\}, \qquad (1)$$

where β is the step change effect to be estimated, and I_t is 0 for 1980 to 2001 and then 1 thereafter. The step change effect on the expected number of fish caught is then exp(β), i.e, the expected number of fish after 2001 is the prediction from equation (1) multiplied by exp(β).

For all models a heterogeneity factor was estimated. This allowed the variation in fish counts to be greater than what is expected on the assumption that the counts follow Poisson distributions. The variance of a count is still, however, assumed to be proportional to the expected value.

Serial correlation between the successive observations could have an effect on the fitting of the various models. This was examined by calculating the correlation between each standardized deviance residual and the following deviance residual. In most cases the second residual was from the same area as the first residual, but one quarter later.

Regression Analysis on Logarithms of CPUE

As noted above, regression analysis was used with the logarithms of mean CPUE values calculated only for samples from areas 1 to 5 that have been sampled since 1980. What was done was to estimate a model with a quartic trend in time, separately for each fish group. This model was then simplified if possible by removing the quartic trend term, then the cubic trend term, etc., if the coefficients were not significant at the 5% level. Once a model for trend was determined a step effect variable was added into the equation allowing the mean to increase or decrease between 2001 and 2002. This was then regarded as estimating the step effect at that time after allowing for any long term trends in the logarithms of CPUE. The regression calculations were carried out in GenStat. The Durbin-Watson test (Durbin and Watson, 1951) was used to check for significant serial correlation. This test can only be used with ordinary linear regression.

Principal Components Analysis

Principal components analysis was also based on the logarithms of the mean yearly CPUE values for sampling areas 1 to 5 only. The principal components are regarded as indices of changes in the fish communities (Manly, 2005b). Their values were therefore subjected to the same type of regression analysis as was used for the individual logarithms of CPUE to see if this indicated any community changes between 2001 and 2002.

Results

Log-Linear Modeling of Midwater Trawl Counts

There are midwater trawl counts for six fish species. Table 1 gives a summary of the model fitted for each species, the estimated step effect, and the serial correlation between each standardized residual for the fitted model and the following standardized residual.

Table 1 Summary of the estimation of the step change effects using log-linear modeling on the midwater trawl counts. The step change parameters were estimated by adding them into a model allowing for month effects, sampling area effects, and a quartic trend varying with the sampling area.

Species	Model Fitted	$\hat{\beta}$	SE($\hat{\beta}$)	exp($\hat{\beta}$)[1]	p-value	Corr[2]
American Shad	Area effects plus quarter effects plus quartic time effects varying with the area.	0.496	0.195	1.643	0.011	0.07
Chinook Salmon	Area effects plus quarter effects plus quadratic time effects varying with the area.	-0.570	0.175	0.565	0.001	-0.05
Delta Smelt	As for American shad.	-0.254	0.342	0.776	0.458	0.04
Longfin Smelt	As for American shad.	0.662	1.444	1.938	0.647	0.25
Striped Bass	As for American shad.	0.441	0.605	1.555	0.466	0.12
Threadfin Shad	As for American shad.	-1.232	0.344	0.292	< 0.001	0.07

[1]exp($\hat{\beta}$) is the estimated step effect on numbers. For example for delta smelt it is estimated that the step effect was to multiply numbers by 0.776, i.e., there was a 22.4% reduction in numbers.
[2]Corr is the serial correlation between one standardized deviance residual and the following one.

There are only three estimated step changes that are significant at the 5% level, for American shad, chinook salmon, and threadfin shad. For American shad the estimated step change represents an increase in numbers of 64%, for chinook salmon the estimated step change represents a decrease in numbers of 43%, and for threadfin shad the estimate represents a decrease of 71%. The directions of change for these fish are consistent with those found when analyzing the fall midwater trawl fish abundance data (Manly, 2005).

The serial correlation between residuals is quite small except for longfin smelt. As the step change is not significant for this fish this is not a concern. (If anything, positive serial correlation will make effects appear to be more significant that they really are.)

Figure 2 shows a comparison between the observed catch per unit effort (CPUE) and the expected CPUE based on the fitted log-linear models. For the construction of this figure only catches from geographical areas 1 to 5 have been considered as sampling was only started in areas 6 and 7 in 1991.

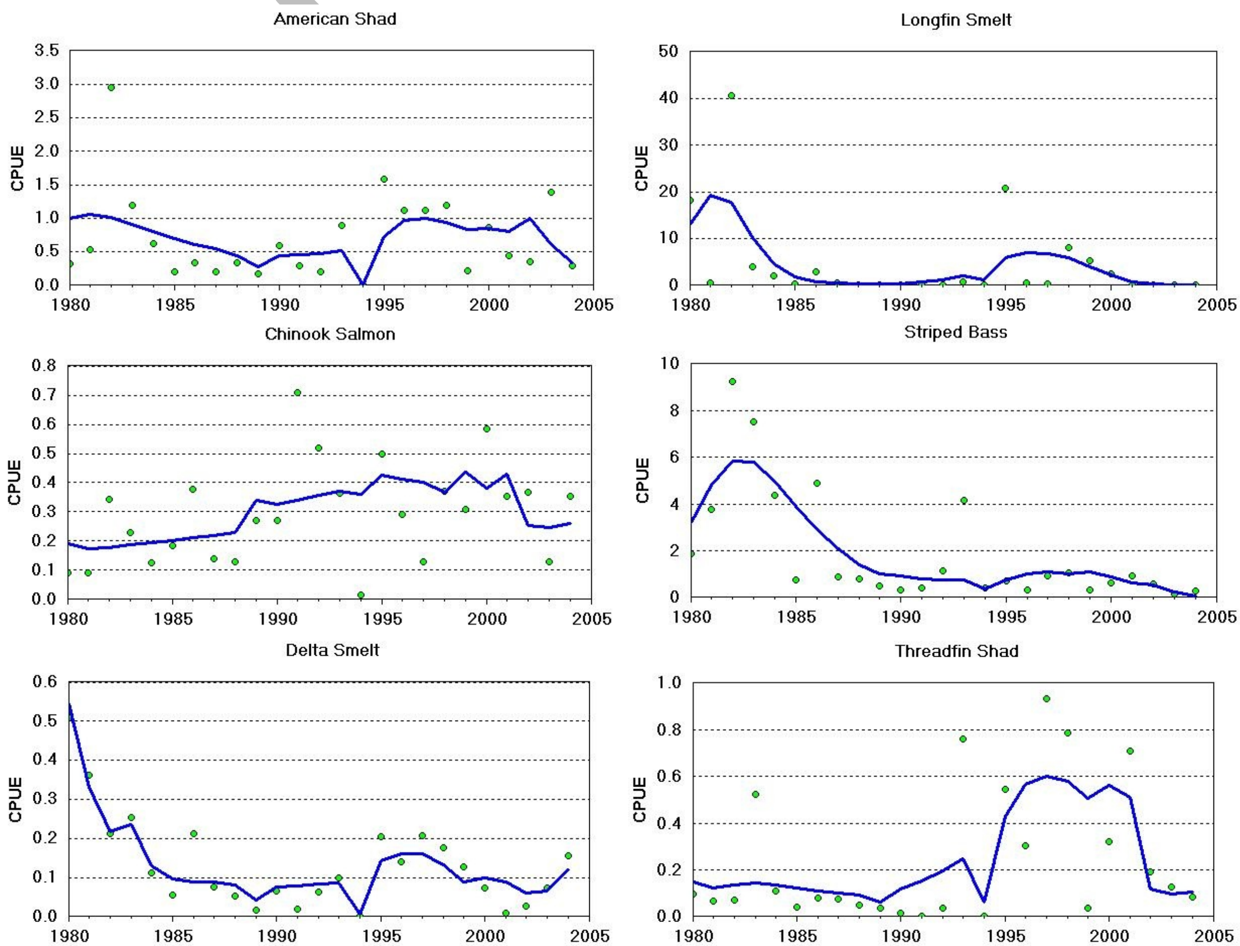

Figure 2 Comparison between the observed mean catch per tow (CPUE) and the expected catch from fitted log-linear models, calculated only for areas 1 to 5 that were sampled in every year from 1980 to 2004 (observed •, fitted —).

The figure shows the significant positive estimated step change for American shad between 2001 and 2002, but the effect is not obvious from the observed means. Similarly, the significant negative step change for chinook salmon is not obvious in the observed means. The significant negative step change for threadfin shad is more apparent.

Regression Analyses with CPUE for Midwater Trawl Counts

Table 2 shows the mean annual CPUE values calculated for areas 1 to 5 only. There are five zero values shown in the table, one for American shad, one for delta smelt, one for longfin smelt, and two for threadfin shad. For the calculation of the natural logarithms of CPUE these zero values were replaced by one half of the minimum non-zero CPUE value for the species concerned. For example, with American shad the minimum positive

CPUE value is 0.173 for 1989. The zero value for 1994 was therefore replaced by 0.173/2 = 0.086.

Table 2 Annual mean catches per trawl (CPUE) for the midwater trawl, 1980 to 2004. The number of tows (various sampling stations in areas 1 to 5 in various months) is denoted by N.

Year	N	American Shad Age 0	Chinook Salmon Age 0	Delta Smelt Age 0	Longfin Smelt Age 0	Striped Bass Age 0	Threadfin Shad
1980	369	0.320	0.092	0.509	18.295	1.886	0.098
1981	411	0.530	0.092	0.363	0.450	3.769	0.068
1982	413	2.949	0.341	0.213	40.584	9.257	0.073
1983	417	1.189	0.228	0.254	3.897	7.525	0.525
1984	420	0.617	0.126	0.112	2.048	4.369	0.112
1985	420	0.207	0.186	0.055	0.421	0.771	0.040
1986	420	0.340	0.379	0.212	2.945	4.876	0.079
1987	427	0.199	0.141	0.075	0.433	0.899	0.077
1988	504	0.333	0.129	0.052	0.204	0.810	0.052
1989	336	0.173	0.271	0.018	0.074	0.494	0.036
1990	378	0.587	0.270	0.066	0.048	0.307	0.016
1991	378	0.291	0.709	0.019	0.019	0.415	0.000
1992	378	0.201	0.519	0.063	0.024	1.151	0.037
1993	378	0.894	0.362	0.098	0.704	4.159	0.759
1994	126	0.000	0.016	0.000	0.000	0.405	0.000
1995	335	1.585	0.499	0.206	20.821	0.713	0.546
1996	378	1.114	0.291	0.140	0.556	0.325	0.304
1997	408	1.118	0.130	0.208	0.324	0.939	0.934
1998	468	1.192	0.370	0.177	8.165	1.047	0.788
1999	420	0.224	0.310	0.129	5.219	0.343	0.036
2000	504	0.863	0.585	0.073	2.583	0.615	0.319
2001	462	0.442	0.353	0.009	0.145	0.946	0.710
2002	462	0.348	0.368	0.026	0.162	0.576	0.190
2003	504	1.389	0.131	0.073	0.063	0.141	0.125
2004	504	0.290	0.355	0.157	0.157	0.280	0.083

The results for fitting regression models to the logarithms of CPUE are summarized in Table 3. No step effects are significant and it is clear that this analysis provides no evidence at all of any step changes in abundance between 2001 and 2002. The Durbin-Watson test gives a non-significant result at the 5% level for all fish except longfin smelt, for which the test statistic is indicative of negative serial correlation but is in the uncertain region where it is not clear whether it is significant or not. Overall, therefore there is not much evidence of serial correlation.

The lack of evidence for a step effect is confirmed by the plots of the observed values for the logarithm of CPUE and the fitted regression relationships that are shown in Figure 3. These plots give no suggestion of any unusual changes between 2001 and 2003, although the fitted regression lines do not always capture well the apparent changes in abundances.

Table 3 Summary of the estimation of the step change effects by linear regression on the logarithms of annual CPUE values for areas 1 to 5 only. The step change parameters were estimated by adding them into a model allowing for overall time trends.

Species	Model Fitted	$\hat{\beta}$	SE($\hat{\beta}$)	exp($\hat{\beta}$)[1]	p-value
American Shad	No time trend.	0.058	0.538	1.060	0.915
Chinook Salmon	No time trend.	0.122	0.503	1.130	0.811
Delta Smelt	Quadratic time trend.	-0.775	1.061	0.461	0.473
Longfin Smelt	Quartic time trend.	-1.073	2.884	0.342	0.714
Striped Bass	Linear time trend.	-0.170	0.633	0.843	0.791
Threadfin Shad	No time trend.	0.171	0.877	1.187	0.847

[1]exp($\hat{\beta}$) is the estimated multiplicative step effect on numbers.

Principal Components Analysis for Midwater Trawl Counts

The principal components analysis for the midwater trawl counts was conducted on the natural logarithms of the values in Table 2, with zero values replaced as described for the regression analysis. The analysis was based on the correlation matrix, which is shown in Table 4. Many of the correlations are large and significant at the 5% level, with no negative correlations.

Table 4 Correlations between the logarithms of mean CPUE values for the midwater trawl, with values that are significant at the 5% level underlined.

	American Shad	Chinook Salmon	Delta Smelt	Longfin Smelt	Striped Bass	Threadfin Shad
American Shad	1.00	0.32	<u>0.54</u>	<u>0.56</u>	0.31	<u>0.65</u>
Chinook Salmon	0.32	1.00	0.15	0.21	0.01	0.27
Delta Smelt	<u>0.54</u>	0.15	1.00	<u>0.72</u>	<u>0.45</u>	<u>0.39</u>
Longfin Smelt	<u>0.56</u>	0.21	<u>0.72</u>	1.00	<u>0.55</u>	<u>0.50</u>
Striped Bass	0.31	0.01	<u>0.45</u>	<u>0.55</u>	1.00	0.28
Threadfin Shad	0.65	0.27	0.39	0.50	0.28	1.00

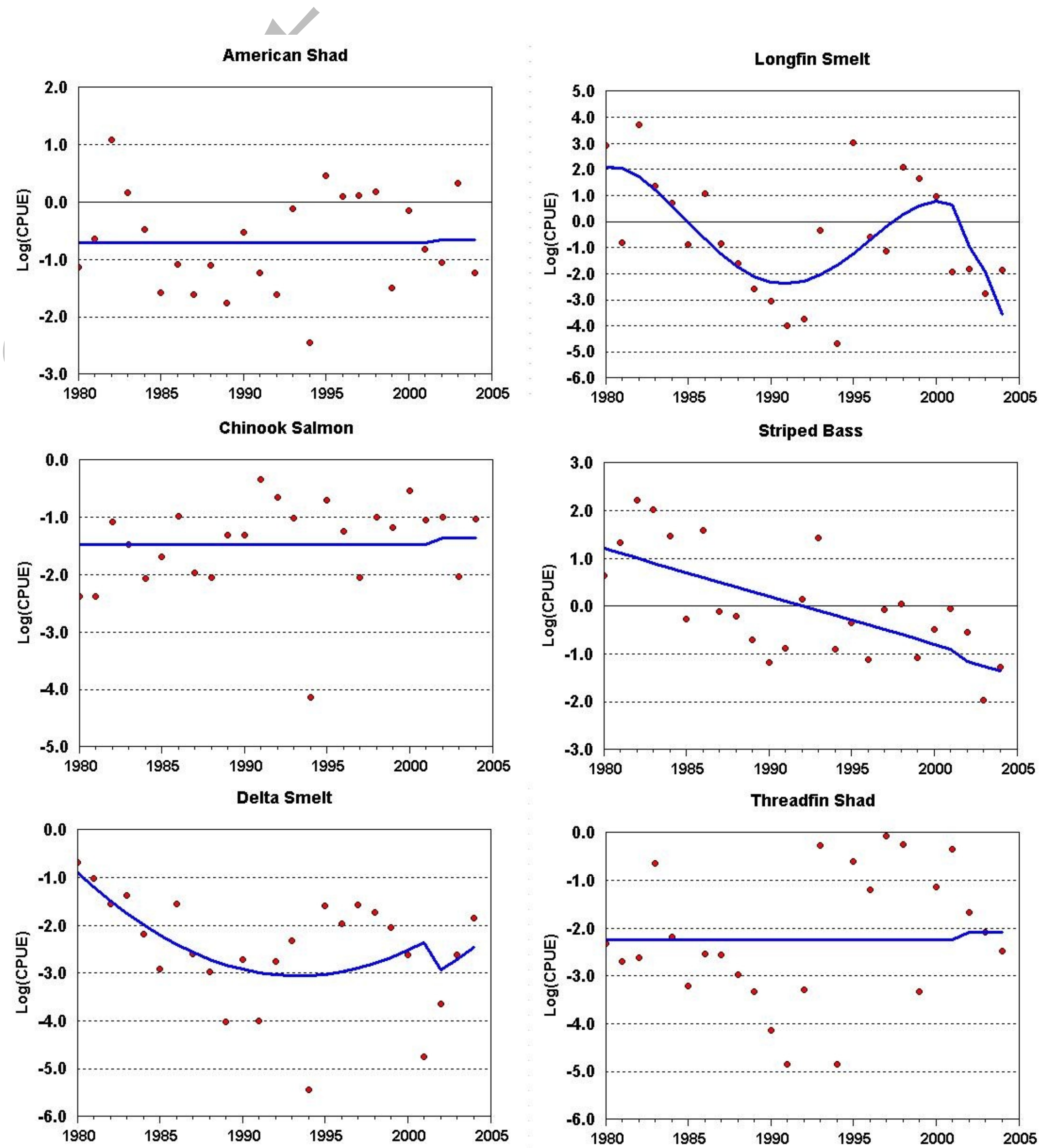

Figure 3 Comparison between the observed mean annual CPUE is areas 1 to 5 (●) and the regression equation fits (—), for midwater trawls.

Table 5 shows the coefficients of the principal components, where these apply to the logarithms of the CPUE variables after they have been standardized to have means of zero and standard deviations of one. The first component (PC1) is clearly an index of overall fish abundance with a positive coefficient of about the same size for all of the fish species. This component accounts for more than half (51.7%) of the variation in the data. The second component (PC2) is mainly a contrast between the abundance of striped bass and the abundance of chinook salmon. This accounts for 18.4% of the variation in the data. Similarly, the other four principal components are also contrasts between the abundance of different fish species. The values of the components themselves (the principal component scores) are shown in Table 6.

Table 5 The results of a principal components analysis on logarithms of CPUE values for midwater trawls.

	PC1	PC2	PC3	PC4	PC5	PC6
AmericanSmelt	0.461	-0.240	-0.342	0.051	-0.738	-0.255
Chinook Salmon	0.208	-0.723	0.640	-0.129	0.031	0.085
Delta Smelt	0.456	0.227	0.152	0.604	-0.023	0.594
Longfin Smelt	0.490	0.191	0.169	0.211	0.418	-0.690
Striped Bass	0.349	0.509	0.314	-0.681	-0.189	0.143
Threadfin Shad	0.418	-0.270	-0.569	-0.328	0.492	0.281
Variance Explained	3.101	1.102	0.680	0.544	0.332	0.241
% Explained	51.7	18.4	11.3	9.1	5.5	4.0
Cumulative %	51.7	70.1	81.4	90.5	96.0	100.0

When regression models allowing for time trends and step effects were considered for the values of the principal components there were few significant effects. For PC1 there were no significant time trends and the step change in the mean between 2001 and 2002 was estimated at -0.795 with a standard error of 1.095. The step effect is therefore not significant ($p = 0.475$). For PC2 there is a very highly significant linear trend ($p < 0.001$) with a step effect estimated at 0.445 with a standard error of 0.55. The step effect is again not significant ($p = 0.427$). The other principal components do not have significant trends or step effects and will not be considered further. The Durbin-Watson test gave no significant results for serial correlation.

Figure 4 shows plots of the values for PC1 and PC2 together with the regression fits. Step changes are not very apparent in these plots although it can be noted that the values of PC1 for 2002, 2003 and 2004 are very similar, and below the mean level up to that time. The trend in PC2 is very apparent and is due to a large extent to the declining numbers of striped bass.

Table 6 Values of the principal component scores for the midwater trawl logarithms of CPUE for areas 1 to 5.

Year	PC1	PC2	PC3	PC4	PC5	PC6
1980	1.17	1.91	0.17	1.03	0.80	-0.03
1981	0.62	1.78	-0.01	0.20	-0.56	0.78
1982	2.94	0.78	0.83	-0.34	-1.28	-1.09
1983	2.44	0.77	-0.14	-0.79	-0.20	0.30
1984	0.84	1.32	-0.03	-0.52	-0.22	-0.18
1985	-1.11	0.42	0.43	0.13	0.39	-0.12
1986	1.06	0.77	1.37	-0.35	0.25	0.28
1987	-0.84	0.68	0.05	0.09	0.62	0.16
1988	-1.04	0.52	-0.20	0.03	-0.08	-0.06
1989	-2.11	-0.41	0.45	-0.39	0.31	-0.17
1990	-1.41	-0.59	0.30	0.81	-1.06	0.05
1991	-2.36	-1.33	1.48	-0.16	-0.87	-0.11
1992	-1.32	-0.51	1.21	-0.45	-0.17	0.96
1993	1.59	-0.24	-0.22	-1.26	-0.01	0.46
1994	-4.73	2.09	-1.31	-0.43	-0.05	-0.69
1995	2.35	-1.00	-0.22	0.58	0.30	-0.61
1996	0.68	-1.04	-0.80	0.72	-0.15	0.12
1997	1.17	-0.01	-1.59	0.10	-0.07	0.76
1998	2.09	-0.65	-0.47	0.12	0.42	-0.23
1999	-0.36	-0.03	0.93	1.25	0.89	-0.54
2000	1.00	-1.31	0.04	0.00	0.31	-0.44
2001	-0.57	-1.29	-0.79	-1.79	0.59	-0.31
2002	-0.78	-1.00	-0.11	-0.61	0.41	-0.03
2003	-0.66	-0.89	-1.64	1.05	-0.93	0.00
2004	-0.66	-0.73	0.30	0.95	0.36	0.70

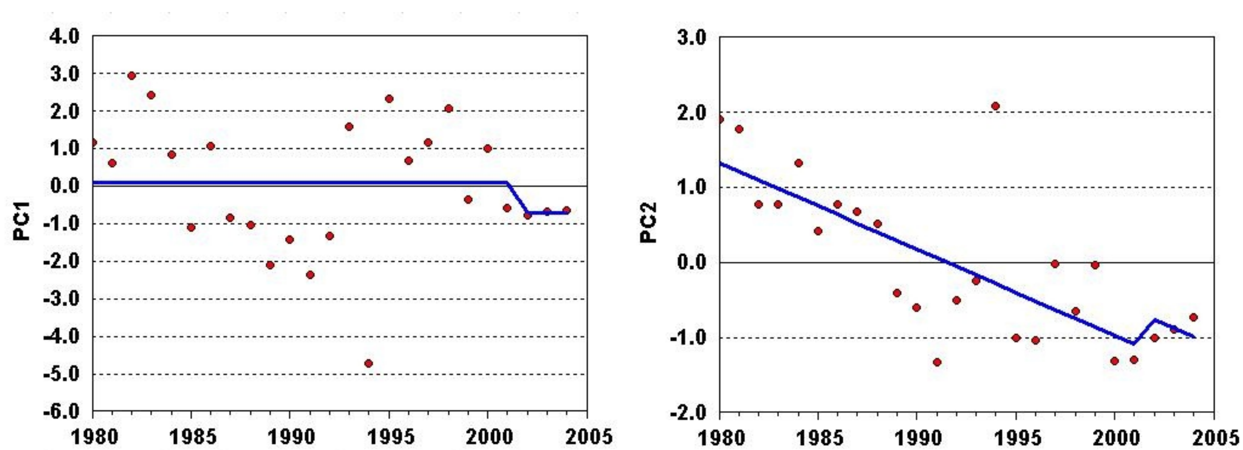

Figure 4 Values of the first two principal components (●) and regression model fits (—) for the logarithms of midwater trawl CPUE in sampling areas 1 to 5.

Log-Linear Modeling of Otter Trawl Counts

For the otter trawl counts are available for 20 fish species, with separate counts for starry flounder with ages 0 and 1. The total counts over all samples are very low in some cases, with the lowest total count being 55 for green sturgeon. As the log-linear trend model of equation (1) includes 38 parameters it is unrealistic to attempt to fit it with such sparse data. For this reason, the log-linear model analysis was only used for the species with more than 1,000 fish counted in total. Even this is a small number when it is considered that there are 607 samples being analyzed (Appendix B). Indeed for one fish with a total count of 1402 (shokihaze gobi) a satisfactory model fit could not be obtained.

Table 7 gives a summary of the results of the log-linear model fitting for the species with a total count of over 1,000 fish other than shkihaze gobi. There are significant positive step effects for longfin smelt age 0, Pacific staghorn sculpin age 0 and starry flounder age 0, and significant negative step effects for striped bass age 0 and yellow gobi age 0.

Figure 5 shows plots of the mean annual CPUE values (the mean fish counts per trawl) and the predicted values for the estimated models. The values are for sampling areas 1 to 5 only as these were the only ones sampled for all of the years 1980 to 2004. Although there are significant step effects estimated between 2001 and 2002, none of the plots in this figure suggest a major change in the system at that time.

All of the estimated correlations between one standardized residual and the next are positive in Table 7, and some of them are quite large. This suggests that the significance levels of the step effects may be exaggerated to some extent. An allowance for the serial correlation could be made in assessing the significance of effects for the cases where this correlation is large. However, as Figure 5 does not really support the idea of any major changes between 2001 and 2002 this seems unnecessary.

Regression Analyses with CPUE for Otter Trawl Counts

The mean annual CPUE values for sampling areas 1 to 5 are shown in Table 8. These were converted to natural logarithms and multiple regression was used to fit models allowing for up to quartic trends with time and a step effect between 2001 and 2002. All of the fish species were not used for this purpose because the CPUE values are very low in some cases, with many zeros. The excluded fish are bigscale log perch (only 99 fish seen in 25 years with 6 zero CPUEs), common carp (28 fish with 12 zeros), green sturgeon (42 fish with 8 zeros), Pacific lamprey (175 fish with 7 zeros), prickly sculpin (113 fish with 9 zeros), redear sunfish (2 fish with 23 zeros), shimofuri gobi (303 fish with 7 zeros), shokihaze gobi (1047 fish with 17 zeros), and splittail age 0 (167 fish with 12 zeros). For the remaining fish that were analyzed any zero CPUE values were replaced by half of the minimum non-zero catch for the other years for the same fish. This was needed for the calculation of logarithms.

Table 7 Summary of the estimation of the step change effects using log-linear modeling on the otter trawl counts. The step change parameters were estimated by adding them into a model allowing for month effects, sampling area effects, and a quartic trend varying with the sampling area.

Species	Model Fitted	$\hat{\beta}$	SE($\hat{\beta}$)	exp($\hat{\beta}$)[1]	p-value	Corr[2]
Channel Catfish	Quartic trend varying with the area.	-0.391	0.242	0.676	0.105	0.00
Longfin Smelt age 0	As for channel catfish.	2.675	0.683	14.518	< 0.001	0.44
Pacific Staghorn Sculpin age 0	As for channel catfish.	0.572	0.216	1.771	0.008	0.06
Shimofuri Gobi	As for channel catfish.	-0.147	0.302	0.863	0.626	0.17
Starry Flounder age 0	Cubic trend varying with the area.	0.929	0.318	2.532	0.003	0.24
Starry Flounder age 1	As for channel catfish.	0.008	0.428	1.008	0.984	0.30
Striped Bass age 0	As for channel catfish.	-1.438	0.311	0.237	< 0.001	0.02
White Catfish	As for channel catfish.	0.260	0.243	1.297	0.285	0.30
Yellow Gobi age 0	As for channel catfish.	-1.328	0.565	0.265	0.019	0.27

[1]exp($\hat{\beta}$) is the estimated multiplicative step effect on numbers.
[2]Corr is the serial correlation between one standardized deviance residual and the following one.

The results from these regression analyses are summarized in Table 9. None of the estimated step effects are at all significant. Partly this may be due to the large standard errors associated with estimates, which are themselves caused by the large amount of apparently random variation in the logarithms of yearly CPUE values. There are some indications of positive and negative serial correlations, but no clearly significant results. There are eight cases where the test result is in the uncertain region where it may or may not be significantly different from zero at the 5% level. Overall there is no clear evidence of serial correlation, although this may be because of the small sample size.

Figure 6 shows plots of the logarithms of the yearly CPUE values and the regression model fits. These do not suggest any step changes between 2001 and 2002, except possibly for striped bass age 0.

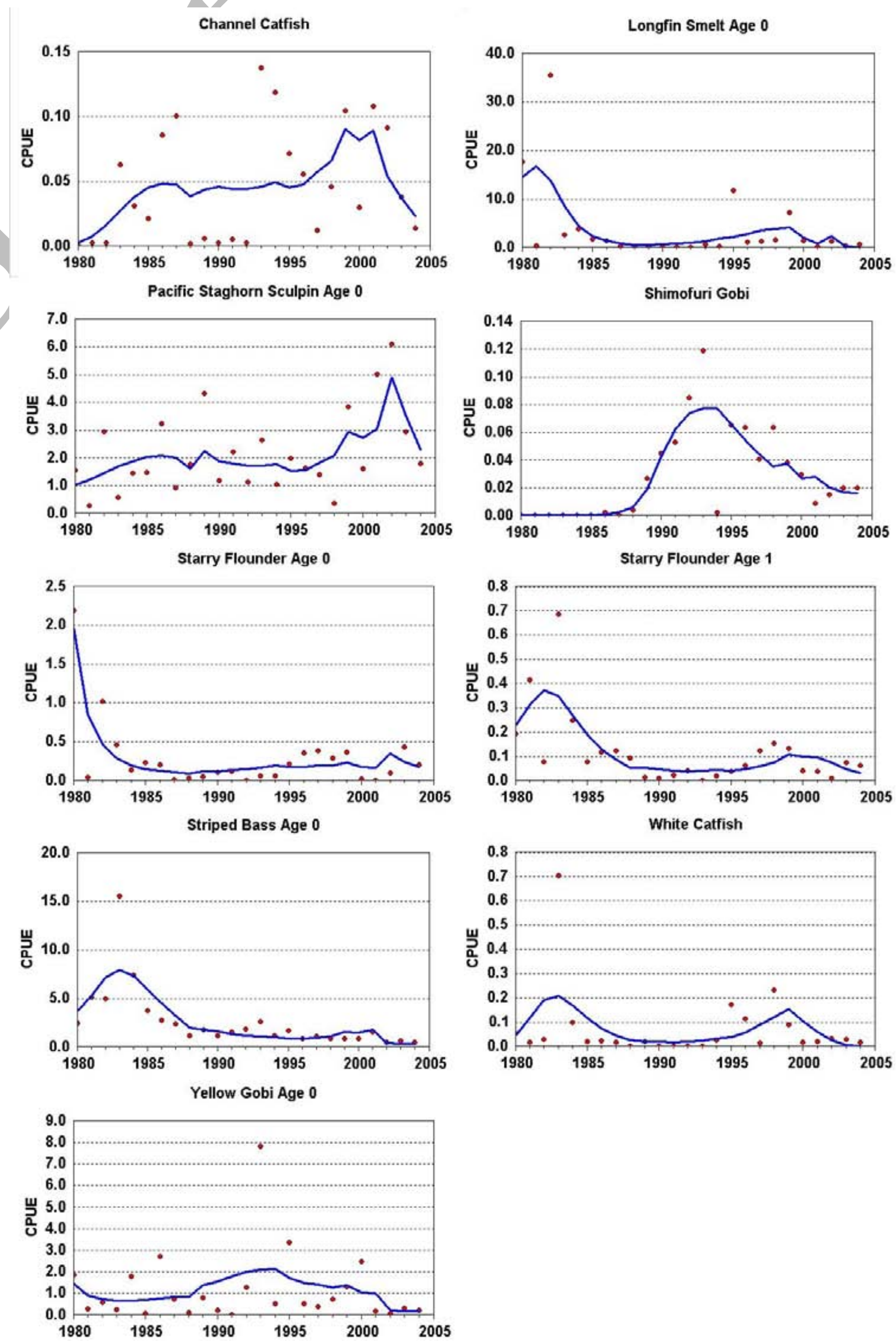

Figure 5 Observed annual mean CPUE (●) and predictions from fitted log-linear models (—) for fish species caught by otter trawls.

Table 8 Mean yearly CPUE (catch per trawls) from otter trawls in sampling areas 1 to 5. Also shown is the total number of trawls (N), the total number of fish caught over the entire period, and the number of years with no catch (zeros).

Year	N	Biglog	Chacat	Comcar	Grestu	Lonsme Age 0	Paclam	Pacssc Age 0	Priscu	Redsun	Rivlam	Shigob	Shogob	Splitt Age 0	Staflo Age 0	Staflo Age 1	Strbas Age 0	Thrsti	Tulper	Whicat	Whistu	Yelgob Age 0
1980	367	0.00	0.00	0.00	0.02	17.74	0.02	1.54	0.01	0.00	0.00	0.00	0.00	0.00	2.19	0.19	2.50	0.01	0.03	0.05	0.01	1.85
1981	401	0.01	0.00	0.00	0.00	0.44	0.09	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.42	5.13	0.00	0.00	0.02	0.00	0.28
1982	405	0.01	0.00	0.01	0.01	35.54	0.02	2.95	0.02	0.00	0.00	0.00	0.00	0.05	1.02	0.08	5.00	0.01	0.01	0.03	0.17	0.59
1983	411	0.04	0.06	0.02	0.01	2.64	0.02	0.58	0.06	0.00	0.02	0.00	0.00	0.03	0.46	0.69	15.52	0.03	0.00	0.71	0.16	0.26
1984	420	0.04	0.03	0.00	0.01	3.88	0.01	1.46	0.02	0.00	0.04	0.00	0.00	0.00	0.14	0.25	7.43	0.00	0.00	0.10	0.21	1.80
1985	420	0.05	0.02	0.00	0.00	1.68	0.00	1.47	0.00	0.00	0.02	0.00	0.00	0.00	0.24	0.08	3.75	0.00	0.01	0.02	0.05	0.07
1986	420	0.00	0.09	0.00	0.00	1.48	0.03	3.24	0.02	0.00	0.02	0.00	0.00	0.02	0.20	0.12	2.78	0.03	0.00	0.02	0.04	2.72
1987	427	0.01	0.10	0.00	0.00	0.37	0.00	0.91	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.12	2.38	0.00	0.00	0.02	0.03	0.73
1988	503	0.00	0.00	0.00	0.00	0.14	0.01	1.77	0.00	0.00	0.03	0.00	0.00	0.00	0.04	0.09	1.16	0.01	0.01	0.00	0.03	0.12
1989	336	0.00	0.01	0.00	0.01	0.10	0.01	4.33	0.00	0.00	0.04	0.03	0.00	0.00	0.05	0.01	1.80	0.02	0.01	0.02	0.03	0.81
1990	378	0.00	0.00	0.00	0.00	0.06	0.00	1.17	0.00	0.00	0.02	0.04	0.00	0.00	0.11	0.01	1.19	0.01	0.00	0.00	0.02	0.22
1991	378	0.00	0.01	0.01	0.00	0.03	0.00	2.23	0.00	0.00	0.01	0.05	0.00	0.01	0.12	0.02	1.54	0.02	0.05	0.00	0.01	0.01
1992	378	0.00	0.00	0.00	0.00	0.06	0.00	1.14	0.01	0.00	0.01	0.08	0.00	0.00	0.00	0.04	1.84	0.02	0.03	0.00	0.00	1.28
1993	378	0.00	0.14	0.00	0.01	0.68	0.00	2.66	0.02	0.00	0.01	0.12	0.00	0.00	0.06	0.00	2.63	0.04	0.06	0.00	0.01	7.80
1994	378	0.00	0.12	0.00	0.00	0.21	0.01	1.06	0.00	0.00	0.01	0.00	0.00	0.00	0.06	0.02	1.16	0.01	0.01	0.03	0.01	0.53
1995	461	0.01	0.07	0.00	0.00	11.82	0.01	1.98	0.02	0.00	0.03	0.07	0.00	0.10	0.21	0.04	1.73	0.03	0.01	0.17	0.04	3.37
1996	504	0.00	0.06	0.00	0.00	1.07	0.00	1.63	0.02	0.00	0.04	0.06	0.00	0.00	0.35	0.06	0.89	0.03	0.02	0.12	0.05	0.51
1997	494	0.00	0.01	0.00	0.00	1.33	0.02	1.40	0.01	0.00	0.06	0.04	0.01	0.01	0.39	0.12	1.10	0.01	0.02	0.01	0.02	0.38
1998	504	0.00	0.05	0.00	0.01	1.63	0.04	0.36	0.05	0.00	0.04	0.06	0.03	0.12	0.29	0.15	0.87	0.02	0.01	0.23	0.07	0.74
1999	420	0.02	0.10	0.00	0.00	7.28	0.00	3.86	0.00	0.00	0.03	0.04	0.03	0.00	0.36	0.13	0.87	0.01	0.01	0.09	0.01	1.31
2000	504	0.00	0.03	0.00	0.00	1.41	0.03	1.61	0.00	0.00	0.08	0.03	0.10	0.02	0.02	0.04	0.84	0.01	0.02	0.02	0.01	2.49
2001	462	0.00	0.11	0.00	0.00	0.18	0.02	5.03	0.00	0.00	0.02	0.01	0.58	0.00	0.00	0.04	1.58	0.02	0.00	0.02	0.00	0.18
2002	460	0.00	0.09	0.00	0.00	1.37	0.00	6.10	0.00	0.00	0.01	0.02	0.43	0.00	0.10	0.01	0.52	0.02	0.01	0.03	0.00	0.09
2003	501	0.01	0.04	0.00	0.00	0.34	0.00	2.93	0.00	0.00	0.02	0.02	0.58	0.00	0.44	0.08	0.61	0.01	0.00	0.03	0.00	0.33
2004	504	0.00	0.01	0.00	0.00	0.72	0.05	1.80	0.00	0.00	0.02	0.02	0.41	0.00	0.20	0.06	0.51	0.04	0.00	0.02	0.01	0.22
Total Fish		99	500	28	42	38251	175	23097	113	2	262	303	1047	167	2991	1233	27154	183	141	765	420	12011
Zeros		6	1	12	8	0	7	0	9	23	3	7	17	12	1	1	0	1	1	5	0	0

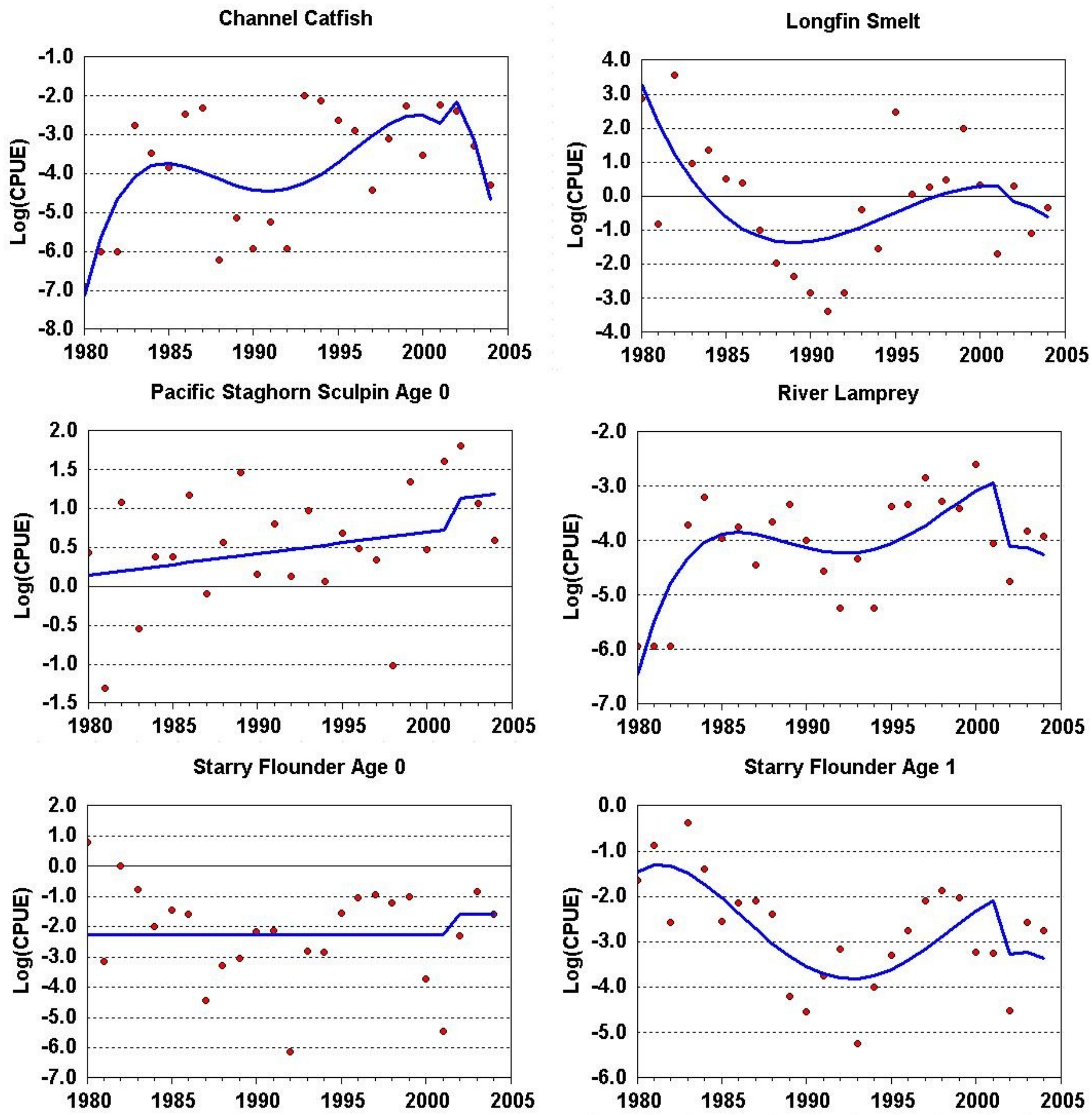

Figure 6 Observed logarithms of mean yearly CPUE (●) and fitted regression curves (—) for otter trawl catches.

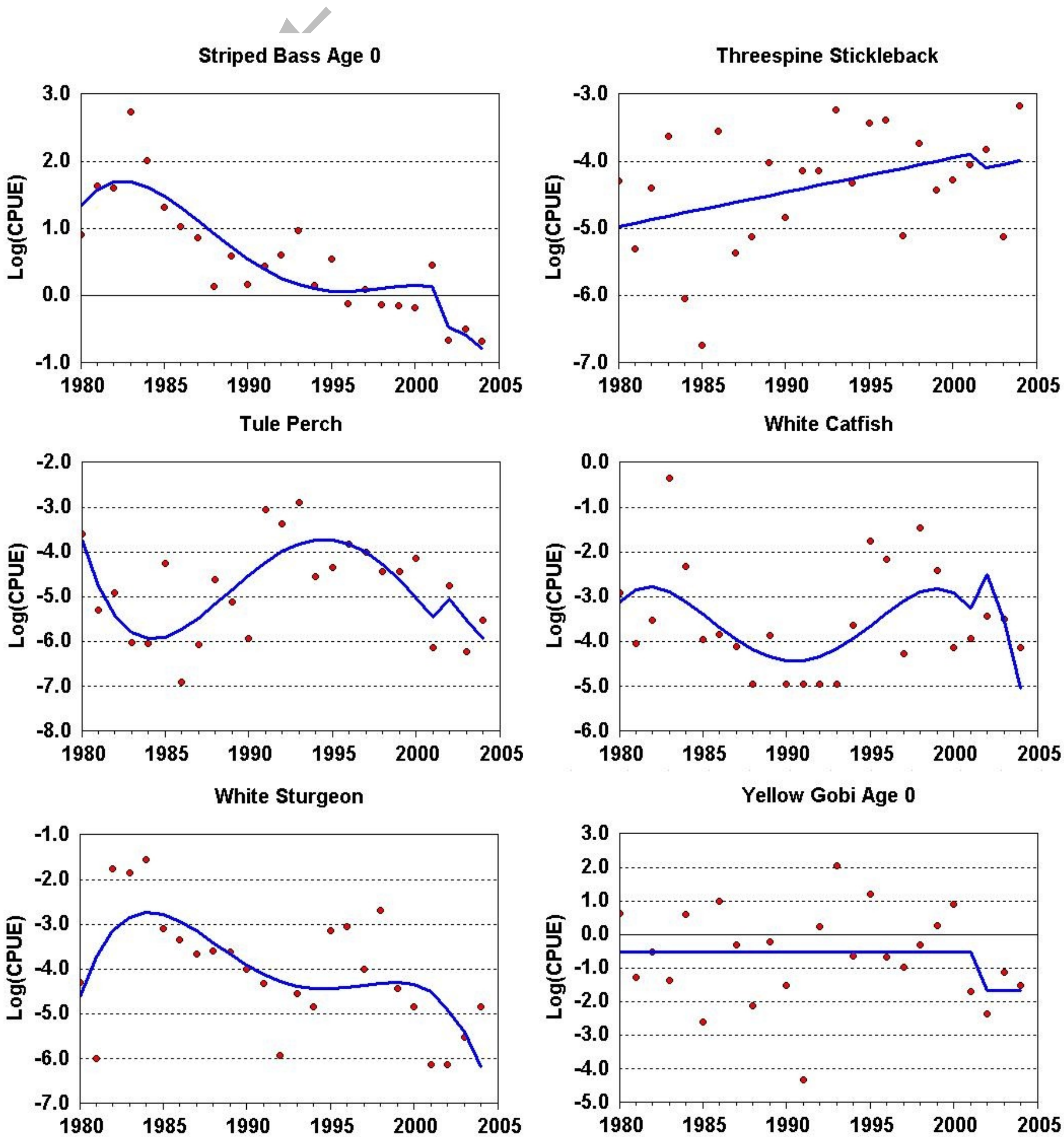

Figure 6, continued.

Table 9 Summary of the estimation of the step change effects using linear regression on the logarithms of means annual CPUE values from otter trawls. The step change parameters were estimated by adding them into a model allowing for up to quartic time trends.

Species	Model Fitted	$\hat{\beta}$	SE($\hat{\beta}$)	exp($\hat{\beta}$)[1]	p-value	D-W[2]
Channel Catfish	Quartic time trend.	1.129	1.985	3.093	0.576	? +
Longfin Smelt age 0	Cubic time trend.	-0.391	2.137	0.676	0.857	NS +
Pacific Staghorn Sculpin age 0	Linear time trend.	0.372	0.540	1.450	0.499	? -
River Lamprey	Quartic time trend.	-1.279	1.098	0.278	0.258	? +
Starry Flounder age 0	No time trend.	0.703	0.998	2.020	0.488	NS +
Starry Flounder age 1	Quartic time trend.	-1.327	1.396	0.265	0.354	? +
Striped Bass age 0	Quartic time trend.	-0.549	0.679	0.577	0.429	? +
Threespine Stickleback	Linear time trend.	-0.246	0.640	0.782	0.704	NS -
Tule Perch	Quartic time trend.	0.866	1.267	2.376	0.503	? -
White Catfish	Quartic time trend.	1.392	1.716	4.025	0.427	? +
White Sturgeon	Quartic time trend.	-0.122	1.764	0.886	0.946	? +
Yellow Gobi age 0	No time trend.	-1.137	0.852	0.321	0.195	NS -

[1]exp($\hat{\beta}$) is the estimated step effect on numbers.
[2]Results of the Durbin-Watson test (NS = not significant at the 5% level, ? = in the uncertain region so it is not clear whether it is significant or not, + = Durbin-Watson statistic indicates positive correlation, - = Durbin-Watson statistic indicates negative correlation).

Principal Components Analysis for Otter Trawl Counts

The 12 CPUE variables analyzed by regression were used for the principal components analysis. Table 10 shows the correlations between these variables, Table 11 shows the principal components obtained, and Table 12 shows the values of the components for the sampled years (the scores).

There are 13 significant correlations (19.6%) out of 66, with one high negative correlation between Pacific staghorn skulpin age 0 and starry flounder age 1. All the other significant correlations are positive.

Table 10 Correlations between variables used for the principal components analysis on logarithms of CPUE for otter trawls in sampling regions 1 to 5. Abbreviations for species names are used, with the full names being bigscale log perch, channel catfish, common carp, green sturgeon, longfin smelt, Pacific lamprey, Pacific staghorn skulpin, prickly sculpin, redear sunfish, river lamprey, shimofuri gobi, shokinhaze gobi, splittail, starry flounder, striped bass, threespine stickleback, tule perch, white catfish, white sturgeon, and yellow gobi. Correlations that are significantly different from zero at the 5% level are underlined.

	ChaCat	LonSme Age 0	PacSSc Age 0	RivLam	StaFlo Age 0	StaFlo Age 1	StrBas Age 0	ThrSti	TulPer	WhiCat	WhiStu	YelGob Age 0
ChaCat	1.00	0.15	0.21	0.42	-0.08	-0.12	-0.13	0.25	-0.21	0.38	0.01	0.25
LonSme 0	0.15	1.00	0.04	-0.02	0.66	0.43	0.27	0.05	0.01	0.62	0.47	0.44
PacSSc 0	0.21	0.04	1.00	0.14	0.00	-0.53	-0.34	0.22	-0.01	-0.23	-0.19	0.00
RivLam	0.42	-0.02	0.14	1.00	0.03	0.01	-0.27	0.04	-0.13	0.24	0.29	0.13
StaFlo 0	-0.08	0.66	0.00	0.03	1.00	0.31	0.08	0.04	0.03	0.50	0.50	0.01
StaFlo 1	-0.12	0.43	-0.53	0.01	0.31	1.00	0.48	-0.31	-0.33	0.53	0.37	0.01
StrBas 0	-0.13	0.27	-0.34	-0.27	0.08	0.48	1.00	-0.26	-0.20	0.27	0.52	0.14
ThrSti	0.25	0.05	0.22	0.04	0.04	-0.31	-0.26	1.00	0.17	0.21	-0.11	0.27
TulPer	-0.21	0.01	-0.01	-0.13	0.03	-0.33	-0.20	0.17	1.00	-0.18	-0.13	0.04
WhiCat	0.38	0.62	-0.23	0.24	0.50	0.53	0.27	0.21	-0.18	1.00	0.51	0.22
WhiStu	0.01	0.47	-0.19	0.29	0.50	0.37	0.52	-0.11	-0.13	0.51	1.00	0.16
YelGob 0	0.25	0.44	0.00	0.13	0.01	0.01	0.14	0.27	0.04	0.22	0.16	1.00

Table 11 Principal components for the otter trawl logarithms of CPUE for sampling regions 1 to 5. Abbreviations for the species names are as in Table 10. The columns of the table are the coefficients for the logarithm of CPUE variables after they are standardized to have a mean of zero and a standard deviation of one.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
ChaCat	0.07	0.46	-0.37	-0.17	-0.02	-0.15	0.01	-0.61	-0.26	0.31	0.18	-0.15
LonSme0	0.41	0.18	0.31	0.03	-0.24	-0.03	0.35	-0.13	0.09	-0.12	0.39	0.58
PacSSc0	-0.19	0.37	0.07	0.32	-0.62	0.09	-0.06	-0.04	0.47	-0.04	-0.08	-0.29
RivLam	0.08	0.35	-0.44	0.27	0.36	0.43	0.08	0.20	0.26	0.18	-0.18	0.34
StaFlo0	0.34	0.09	0.35	0.49	-0.01	-0.13	0.03	0.10	-0.39	0.44	-0.36	-0.10
StaFlo1	0.40	-0.27	-0.16	-0.02	0.13	-0.25	0.30	0.12	0.49	0.32	0.24	-0.40
StrBas0	0.31	-0.31	-0.03	-0.33	-0.30	0.20	-0.43	-0.23	0.21	0.32	-0.34	0.26
ThrSti	-0.05	0.43	0.25	-0.26	0.18	-0.36	-0.50	0.37	0.18	0.22	0.19	0.11
TulPer	-0.14	0.04	0.58	-0.04	0.47	0.33	0.05	-0.46	0.27	0.09	-0.01	-0.16
WhiCat	0.44	0.21	-0.05	-0.02	0.21	-0.31	-0.11	-0.17	0.16	-0.60	-0.43	-0.10
WhiStu	0.41	-0.00	-0.02	0.17	0.02	0.46	-0.45	0.08	-0.18	-0.20	0.47	-0.30
YelGob0	0.16	0.30	0.13	-0.59	-0.14	0.35	0.36	0.33	-0.16	-0.01	-0.20	-0.27
Root[1]	3.5	2.2	1.5	1.1	0.9	0.9	0.7	0.6	0.3	0.2	0.1	0.1
%[2]	28.8	18.5	12.2	9.4	7.7	7.2	5.5	4.6	2.7	1.4	1.2	0.7
Cum %[3]	28.8	47.2	59.4	68.9	76.5	83.7	89.3	93.9	96.6	98.1	99.3	100.0

[1]Variance of the principal component (PC).
[2]Percentage of the total variance accounted for by the PC.
[3]Cumulative percentage for components up to and including PCi.

Principal component 1 (PC1) accounts for 28.8% of the variation in the data. Based on the large coefficients (outside the range -0.3 to +0.3) shown in Table 11 it is an index of the abundance of longfin smelt aged 0, starry flounder aged 0 and 1striped bass aged 0, white catfish and white sturgeon.

Table 12 The values of the principal components (the scores) for the otter trawl logarithms of CPUE for sampling regions 1 to 5.

Year	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
1980	1.73	-1.06	3.32	-0.08	-0.49	-0.59	0.94	0.51	0.23	-0.05	-0.41	-0.22
1981	0.16	-3.81	0.03	-1.55	0.32	-1.36	0.82	0.05	-0.07	0.31	-0.27	0.36
1982	2.16	-0.94	2.38	0.52	-2.01	0.19	-0.68	0.20	-0.16	-0.36	0.75	0.12
1983	4.39	-0.49	-1.10	-0.59	0.62	-1.08	-1.81	-0.28	0.56	0.31	-0.41	0.20
1984	3.13	-0.69	-1.56	-0.07	-0.86	1.53	0.24	-0.22	0.10	-0.36	-0.21	-0.14
1985	0.70	-1.82	-0.40	1.51	-0.28	1.19	0.40	-1.74	-0.21	0.08	-0.02	0.25
1986	1.10	1.26	-1.04	-0.55	-1.55	-0.21	-0.32	1.13	-0.15	0.87	0.27	-0.23
1987	0.04	-0.99	-1.90	-1.14	-0.42	0.14	0.35	-0.46	-0.54	-0.10	0.74	-0.34
1988	-1.26	-1.57	-0.40	1.08	0.44	0.88	-0.03	0.67	0.59	-0.14	0.48	-0.21
1989	-1.29	0.64	-0.35	0.24	-0.51	1.09	-1.05	0.98	0.35	-0.45	-0.67	-0.17
1990	-1.76	-1.13	-0.54	0.79	-0.07	0.53	-0.66	1.21	-1.31	-0.32	-0.42	0.40
1991	-2.51	-1.29	0.91	1.56	0.90	-0.04	-1.64	-0.77	0.42	0.51	0.04	-0.21
1992	-2.83	-1.49	0.73	-2.26	0.55	0.36	0.14	0.24	0.84	-0.43	-0.01	-0.31
1993	-1.57	2.05	1.52	-1.96	-0.34	1.42	-0.50	-0.73	-0.59	0.85	-0.20	0.08
1994	-1.22	0.17	0.05	-0.88	0.22	-0.69	-0.15	-0.97	-1.25	-0.23	-0.01	-0.35
1995	1.67	2.32	0.64	-0.59	0.26	0.33	-0.06	-0.08	0.06	-0.51	-0.09	0.40
1996	0.80	1.65	0.45	0.49	1.39	-0.12	-0.50	-0.11	0.09	-0.11	0.10	-0.38
1997	0.21	-0.15	0.02	1.21	0.92	0.90	1.04	0.11	0.21	0.71	0.03	0.17
1998	2.02	0.71	-0.19	-0.18	2.48	-0.45	0.02	0.24	-0.60	-0.45	0.29	-0.08
1999	1.01	1.89	0.15	0.57	-0.14	-0.24	1.29	-0.48	0.59	0.04	-0.10	-0.33
2000	-0.86	1.29	-0.39	-0.61	0.80	1.12	1.15	0.37	0.40	0.01	0.15	0.57
2001	-2.20	0.68	-1.87	-0.54	-1.19	-1.05	-0.25	-0.43	1.01	-0.18	0.06	0.21
2002	-2.10	1.66	0.48	0.99	-0.84	-1.58	0.08	-1.01	0.01	-0.48	0.01	0.35
2003	-0.60	0.38	-1.05	1.32	-0.57	-1.01	1.15	0.33	-0.47	0.15	-0.67	-0.40
2004	-0.91	0.73	0.08	0.71	0.38	-1.26	0.02	1.22	-0.11	0.34	0.58	0.25

PC2 is a contrast between the abundance of channel catfish, Pacific staghorn skulpin, aged 0, river lamprey, threespine stickleback and the abundance of striped bass aged 0. Similarly, the other principal components are comparisons between the abundances of different groups of fish.

When the principal component scores were used as the dependent variables for regression equations allowing for trend and a step change between 2001 and 2002, there were no significant step changes. Also, there were no significant trend effects for PC4, PC5, and PC7 to PC12. Figure 7 shows the observed scores and the fitted regression equations for PC1 to PC6, which account for 84% of the variation in the data. There are no indications of step changes between 2001 and 2002 in any of the plots. Serial correlation was not an issue with these regressions. The Durbin-Watson statistic was not significant for nine of the variables and in the uncertain region for the other three regressions.

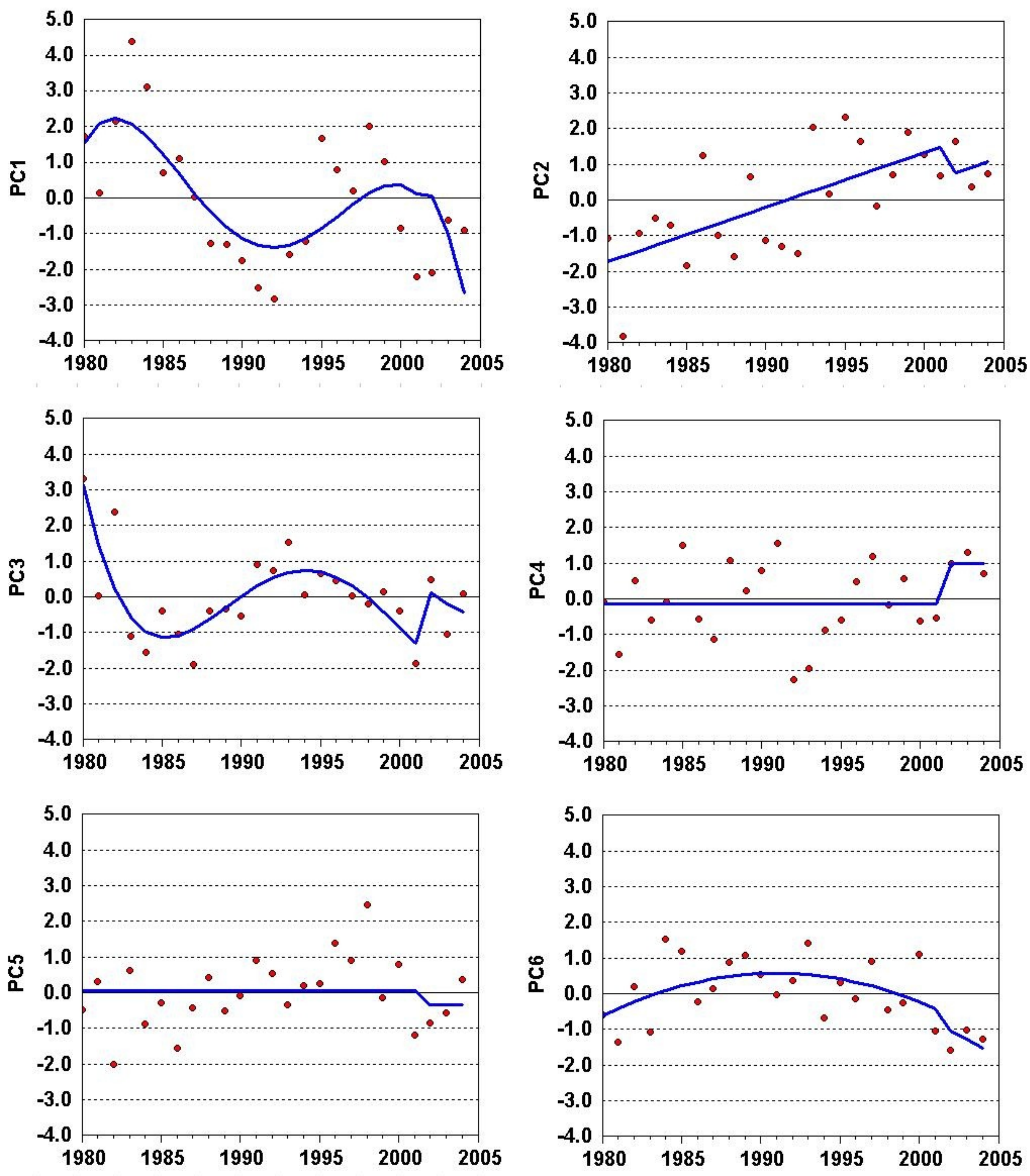

Figure 7 Principal component scores (●) for the otter trawl logarithms of CPUE for sampling areas 1 to 5 with fitted regression lines (—).

Discussion

Although there appear to have been clear changes in the abundances of some species over the period from 1980 to 2004, the analyses considered here have given only limited evidence of step changes between 2001 and 2002, from the log-linear modeling analyses only. In this respect it is useful to consider the summary shown in Table 13 of the estimated step effect parameters from the fall midwater trawl data as reported by Manly (2005a), the Bay Study midwater trawls, and the Bay Study otter trawls. There are few significant results with the linear regression analyses, but that is not surprising given that these were done on mean annual CPUE and therefore there is much less data than with the log-linear modeling. In general the estimates that are significantly different from zero are consistent in direction. The exception is longfin smelt. The data from the Fall Midwater Trawl indicates a very significant drop for these fish for all age classes but the Bay Study otter trawl data indicate a very significant increase in the longfin smelt age 0.

For the Bay Study the log-linear model analyses were carried out on data from areas 1 to 7 as shown on Figure 1. However, the regression analyses were carried out on the data from areas 1 to 5 only because areas 6 and 7 were not sampled before 1991. This could account for some differences between estimated step effects from the two types of analysis.

This possibility has not been examined in detail, but the data from areas 6 and 7 do not show any clear pattern of changes between 2001 and 2002. This is shown in Figure 8, which gives logarithms of mean annual CPUE values for areas 6 and 7 only for the years 1991 to 2004. There is some appearance of the variation in the CPUE values being lower at the end of the period than at the start. This can be explained by the fact that only 36 sample observations are available for estimating the mean CPUE values for 1991 to 1993, only 12 values in 1994, and then the number increased from 75 in 1995 to 120 in 2003 and 2004.

All of the analyses reported here are based on the assumption that step changes in fish numbers may have occurred between 2001 and 2002. Based on this assumption the magnitude of the possible change has been estimated in various different ways. A different but more complicated analysis is possible which considers that a step change may have occurred but does not specify when. There is a considerable literature on this change point problem (Manly, 2001, p. 205). This recognizes the fact that if a time series is observed, there appears to be a change in mean between times t_{i-1} and t_i, and a test is made for a change at that point only, then there may be a high probability of obtaining a significant result even when the series actually has no changes in the mean at any time.

Table 13 Summary of estimates of parameters for a step effect between 2001 and 2002 for the Fall Midwater Trawl sampling and the Bay Study sampling. Underlined cases are where the estimated step effect is significantly different from zero at the 5% level.

	Fall Midwater Trawl				Bay Study Midwater Trawl				Bay Study Otter Trawl			
	Log-linear Model		Linear Regression		Log-linear Model		Linear Regression		Log-linear Model		Linear Regression	
Fish	b[1]	SE(b)	b	SE(b)	b	SE(b)	b	SE(b)	b	SE(b)	b	SE(b)
American Shad	1.74	0.27	0.41	0.50								
American Shad age 0					0.50	0.20	0.06	0.54				
Channel Catfish									-0.39	0.24	1.13	1.99
Chinook Salmon	-1.31	0.45	-0.96	0.56								
Chinook Salmon age 0					-0.57	0.18	0.12	0.50				
Delta Smelt	-1.38	0.44	-1.37	0.86								
Delta Smelt age 0					-0.25	0.34	-0.78	1.06				
Longfin Smelt	-5.84	1.04	-0.22	1.13								
Longfin Smelt age 0					0.66	1.44	-1.07	2.88	2.68	0.68	-0.39	2.14
Pacific Staghorn Skulpin									0.57	0.22		
Pacific Staghorn Skulpin age 0											0.37	0.54
River Lamprey											-1.28	1.10
Shimofuri Gobi									-0.15	0.30		
Splittail	-2.27	0.53	-1.42	0.90								
Starry Flounder age 0									0.93	0.32	0.70	1.00
Starry Flounder age 1									0.01	0.43	-1.33	1.40
Striped Bass age 0	-3.00	0.94	-1.58	0.51	0.44	0.61	-0.17	0.63	-1.44	0.31	-0.55	0.68
Striped Bass age 1	-0.76	0.41	-0.36	0.34								
Threadfin Shad	-2.69	0.24	-2.04	0.53	-1.23	0.34	0.17	0.88				
Threespine Stickleback											-0.25	0.64
Tule Perch											0.87	1.27
White Catfish	2.27	0.82	2.23	1.85					0.26	0.24	1.39	1.72
White Sturgeon	-2.21	0.84	-0.08	0.64							-0.12	1.76
Yellow Gobi age 0									-1.33	0.57	-1.14	0.85

[1]The estimated step parameter is b, with standard error SE(b). The interpretation of b is that between 2001 and 2002 the fish abundances are multiplied by exp(b). Hence if b is negative there is an estimated drop in abundance and if b is positive then their is an estimated increase.

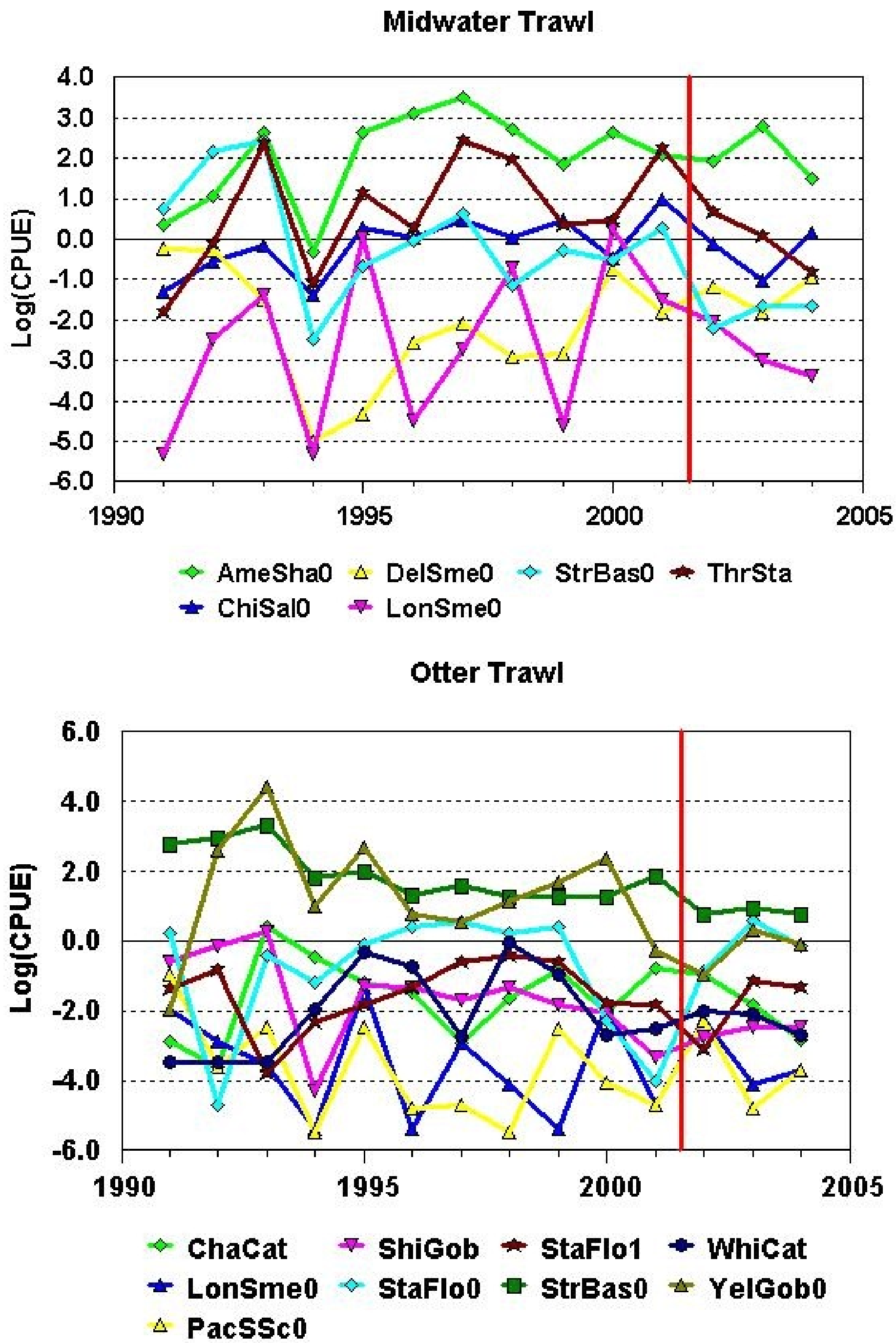

Figure 8 Natural logarithms of mean annual CPUE values for samples from areas 6 and 7, where sampling began in 1991. Any zero CPUE values were replaced with half of the minimum CPUE for the non-zero years for the species where necessary.

The reason for this is essentially a multiple testing problem. A series of length n has n - 1 potential change points. If n is reasonably large then one of these potential change points may look like a real change by chance alone, even with completely random series. Therefore, for a change point analysis what should really be done is to compare the size of the change at a potential change point with the distribution expected for the maximum observed change from all n - 1 possible change points based on a null model for which there are in fact no change points at all.

A recent paper by Solow and Beet (2005) contributes to the literature on change point analysis with a method for testing for a change in a whole ecosystem. It would be very valuable if this could be used with the data from the Sacramento-San Joaquin Delta, but unfortunately their method does not apply for systems that are displaying trends. (In fact, this seems to be a problem with their example.)

Results from these types of analysis will be described in a separate report. One such analysis has been done so far based on the log-linear model for threadfin shad from the Bay Study midwater trawl, for which the estimated step effect between 2001 and 2002 is very highly significant. Indeed, the t-value for the estimated step effect is -1.232/0.344 = -3.58 (Table 1). The probability of a value that far from zero by chance alone is then only 0.00036 based on the usual theory used for assessing these models. Serial correlation does not appear to be an issue.

For the new analysis the null model was the estimated log linear model with effects for the sampling area and quarters of the year, and quartic time trends varying with the sampling areas, as in Table 1. The parameters were set equal to those for this model for the original threadfin shad data. This null model has no step changes. Based on the model, 1,000 new sets of data were generated using bootstrap resampling of model residuals, to compare with the original data.

For both the original data and the simulated data step changes were estimated for each possible time of change, i.e. between 1980 and 1981, between 1981 and 1982, ... between 2003 and 2004. For each of the 24 possible change points an F-statistic was calculated to measure the magnitude of the change, i.e. $F = t^2 = \{b/SE(b)\}^2$, where b is the estimated step change parameter as in Table 1. Also, the maximum of these statistics, F_{max}, was calculated for all data sets.

For the original threadfin shad data the maximum estimated change based on the F statistics was not between 2001 and 2002. Indeed there are larger estimated changes for 1992 to 1993, 1993 to 1994, 1994 to 1995, 1996 to 1997, 1998 to 1999, and 2000 to 2001. The most significant estimated step change based on its F-value is for 2000 to 2001, with a large positive change estimated.

By comparison with the simulated null model data the maximum step change in the observed threadfin shad data has a probability of about 0.016 of occurring by chance.

This then gives evidence that these observed data do not match the null model very well. There are nine individual change points for the original data for which the probability of an F-value as large as that observed is 0.05 or less, but these do not include the 2001 to 2002 change point. For that point the probability of an F-value as large as the observed one is estimated to be 0.127.

This is a preliminary analysis on one fish species only. It suggests that the original set of data displays changes between years that are not consistent with a null model for which the underlying trends are well approximated by a quartic polynomial. In comparison with the null model the original data display changes between one or more years that can be interpreted as step changes rather than changes reflecting an underlying smooth trend. There is, however, little evidence for a change point between 2001 and 2002.

One thing that the simulated data demonstrate, unfortunately, is that the asymptotic theory usually used to interpret the results from log-linear models is not very effective with the threadfin shad data. This is likely due to the large number of zero and small observed counts. For example, the usual t-test suggests that the probability of getting an estimated step change parameter as far from zero as the observed one for 2001 to 2002 is only 0.00036. However, for this change point the simulations indicate that the probability is very much larger at 0.127. Similarly, the largest estimated step change parameter is for 2000 and 2001. The estimate is 2.073 with a standard error of 0.280, giving $F = (2.073/0.280)^2 = 54.88$. According to the F-distribution the probability of a value that large is $1.94\text{x}10^{-13}$. Nevertheless, an F-value larger than 54.88 occurred once in the 1,000 simulated sets of data for the 2001 to 2002 step change, and 15 times altogether for all possible times for the step change, i.e 15 times for 24,000 F-values. This indicates that such a large value is unlikely to occur, with a probability of only about 0.0006, but this is very much larger than $1.94\text{x}10^{-13}$.

All of this indicates that the significance levels for estimated effects with log-linear modeling presented in this report and the earlier one (Manly, 2005a) should be regarded with caution for the present.

Conclusion

The evidence for a step change in fish numbers between 2001 and 2002 is not as clear from the Bay Study data as it was from the Fall Midwater Trawl data. Log-linear modeling gives significant step effects for three out of six fish types for the Bay Study midwater trawl, and for five out of nine fish types for the Bay Study otter trawl. However, plots of the data with the fitted values from the models only indicate an obvious step effect for threadfin shad from the midwater trawl. Linear regressions on mean annual CPUE give no significant estimated step effects at all. Principal components analyses on the midwater trawl and otter trawl mean annual CPUE values gave no evidence of a step effect between 2001 and 2002 in the community structure.

Thus, all of the evidence for a step change comes from log-linear model analyses. Unfortunately, however, the preliminary simulation study suggests that standard methods for assessing the significance of these step effects may not be reliable for data of the type being considered, and that, in any case, testing for step effects should consider all possible times of change. The significant step effects obtained for the Bay Study from log-linear models should therefore be viewed with some caution at this time.

References

Durbin, J. and Watson, G.S. (1951). Testing for serial correlation in least squares regression. *Biometrika* 38: 159-78.

Lawes Agricultural Trust (2005). *GenStat 8th Edition*. VSN International Ltd., www.vsn-intl.com

Manly, B.F.J. (2005a). *Analyses A: Log-Linear Modeling, Linear Regression, and Principal Components Analysis for Fall Midwater Trawl Fish Counts, 1967-2004*. Report prepared for the Interagency Ecological Program, California, by Western EcoSystems Technology, Inc.

Manly, B.F.J. (2001). *Statistics for Environmental Science and Management*. Chapman and Hall/CRC, Boca Raton.

Manly, B.F.J. (2005b). *Multivariate Statistical Methods: a Primer*, 3rd Edit. Chapman and Hall/CRC, Boca Raton.

Solow, A. and Beet, A.R. (2005). A test for a regime shift. *Fisheries Oceanography* 14: 236-240.

Analyses C: Change Point Analyses of the Fall Mid-Water Trawl and the Bay Study Fish Counts

Bryan F.J. Manly
Western EcoSystems Technology Inc.
bmanly@west-inc.com

Contents

Summary 2

Introduction 4

Methods 5

Results for the Fall Midwater Trawl Samples 8

Results for the Bay Study Samples 11

Conclusion 11

References 11

Summary

- The change point problem is described. This is concerned with deciding whether any step changes in a time series are significant without defining in advance where a change might have occurred. The approach needed is then to compare all possible estimated step changes with distribution of the largest step change expected by chance in a series where there are in fact no changes.

- The change point analysis used here involves a Monte Carlo approach that allows for trends in the data. It has been applied to the Fall Midwater Trawl (FMWT) data (1967-2004) and the Bay Study data (1980-2004). The particular interest was in whether changes between 2001 and 2002 are significant when considered in this way.

- Data were generated from a null model with no change points. Log-linear models were estimated separately for each series of fish counts, allowing for effects due to the area sampled, time trends, and the quarter of the year (for the Bay study data). Time trends were allowed to vary with the sampling area if necessary. A maximal model was fitted that allows for these effects and then simplified by removing non-significant terms. The resulting model had no step effects and served as the null model for the fish counts being considered. Data were generated from this model to determine the distribution of estimated step change parameters when there are actually no step changes, and the distribution of the most significant of these estimates.

- Once a null model was defined, 1000 sets of data were generated from this model. For each set of data step change parameters were estimated for every possible time for a change. The magnitude of a step change parameter was then measured by an F-statistic equal to the square of the estimate divided by its standard error. For each generated set of data the maximum F-statistic was also determined from all possible change points. The significance of the estimated step change parameters for the real data was then estimated by comparing the observed F-values to the distribution of the same values for the generated data, and also the distribution of the maximum F-values for the generated data.

- Bootstrapping of residuals was used to produce the generated sets of data. This required a special stratified resampling method.

- The analysis was tested on an independently generated set of data with no step changes and gave exactly the type of result expected.

- For both the FMWT and Bay Study data it is apparent that the significance of estimated step changes is far less from the Monte Carlo method than it is using the usual methods of log-linear modeling. This is probably due to the sparse nature of the data, with many zero counts. Nevertheless, there are still many significant estimated changes with the real data, even when significance is assessed using the distribution

of the maximum F-statistic from all possible times of changes. These changes are, however, not generally between 2001 and 2002. It is therefore concluded that the fish abundances have experienced step changes in the past, but the changes observed between 2001 and 2002 are not particularly unusual in this respect, with larger changes apparently having occurred at other times.

Introduction

When considering the possibility of a step change in an ecosystem based on time series of the abundance of organisms there are two approaches that can be taken. One approach is to assume that the time of the step change is known. The magnitude of the step change can then be estimated using standard regression methods. This is then a relatively straightforward type of analysis. It can, however, be argued that this analysis is biased, particularly if the time used for the step change is based on an inspection of the data, because there is a multiple testing problem. A series of length n has n - 1 potential change points. If n is reasonably large then one of these potential change points is likely to be significantly large by chance alone, even with completely random series, unless an allowance for the multiple testing is made. Therefore, what should really be done is to compare the size of the change at a potential change point with the distribution expected for the maximum observed change from all n - 1 possible change points, based on a null model for which there are in fact no change points at all.

There is a considerable literature on the change point problem and how to allow for the multiple testing (Manly, 2001, p. 205). A recent paper by Solow and Beet (2005) contributes to this literature with a proposal for a Monte Carlo method for testing for a change in a whole ecosystem. It would be very valuable if this could be used with the data from the Sacramento-San Joaquin Delta, but unfortunately their method does not apply for systems that are displaying trends. In fact, this seems to be a problem with their example.

The approach used here for a change point analysis also uses a Monte Carlo method, but allows for underlying trends in the data. It has been applied to the fish counts from the Fall Midwater Trawl (FMWT) study and the Bay Study data, for the species that have a reasonable nunber of positive counts and show a significant step change between 2001 and 2002 using ordinary log-linear modeling. The FMWT study provides samples for the years 1967 to 2004, except for 1974 and 1979. The Bay Study provides samples for the years 1980 to 2004.

Essentially what has been done is to fit a log-linear model to the time series of fish counts for a species, allowing for effects for the area sampled, time trends that may vary with the area, and effects for the quarter of the year when sampling took place (for the Bay Study data). This model has no step changes, and it becomes the null model for the analysis. Many sets of data are generated using this null model, and the log-linear model fitted to the real data is also fitted to the simulated data. In this way the distributions of estimated step changes are approximated for all possible times of a step change when in fact no step changes occur. The distribution of the maximum step change for all possible change point times is also approximated, again for the situation where no step changes actually occur.

By comparing an estimated step change at one point in time for the original data with the generated distributions of estimates of the step change at the same time from the null model it is possible to estimate the probability of obtaining a step change as large as the observed one by chance alone.

It is also possible to compare the observed step change at one time point with the distribution of maximum estimated step changes from the generated data. If an observed step change is significantly large in comparison with the null model distribution of maximum changes then it certainly provides evidence of a real change point at the time being considered.

Methods

The determination of a null model for each fish count followed the approach described in earlier reports (Manly, 2005a, 2005b). For the FMWT data the most complicated model considered allows for a quartic time trend that varies from area to area. Hence in area i the expected number of fish of species j caught in year t took the form

$$E(Y_{ij}) = \exp\{\log_e(N) + \alpha_{0ij} + \alpha_{1ij}t + \alpha_{2ij}t^2 + \alpha_{3ij}t^3 + \alpha_{4ij}t^4\}, \quad (1)$$

where $\log_e(N)$ is the offset that takes into account the number of trawls made, and the α parameters are estimated. To reduce the correlation between the polynomial terms, t was set equal to the year minus 1985. Depending on the result of significance tests some of the powers of t were removed from the above equation. Also, in some cases the coefficients of the powers of t could be the same in all areas.

For the Bay Study data there was an extra factor for the sampling quarter within years. For each type of fish count what was done was to first fit a model allowing for differences between counts in different quarters of the year and quartic time trends varying with the area. The expected count for the fish in area i in quarter j of year t then took the form

$$E(Y) = \exp\{\log_e(N) + \alpha_{0ij} + \alpha_{1ij}t + \alpha_{2ij}t^2 + \alpha_{3ij}t^3 + \alpha_{4ij}t^4 + q_j\}, \quad (2)$$

where $\log_e(N)$ is the offset that takes into account the number of trawls made, and the α parameters are estimated, as are the quarter effects q_j. To reduce the correlation between the polynomial terms, t was set equal to the year minus 1992. Depending on the result of significance tests some of the powers of t were removed from the above equation. Also, in some cases the α coefficients could be made the same in all areas. Quarter effects were assumed to always exist.

The fitted model for a fish count was the null model for Monte Carlo tests. Based on the model, 1,000 new sets of data were generated using bootstrap resampling of model residuals, to compare with the original data. For both the original data and the simulated data step changes were estimated for each possible time of change (between the first and second year, between the second and third year, etc.). These estimates were obtained by adding a term βI_t into the right-hand side of equation (1) or equation (2), as appropriate, where β is the estimated step change and I_t is zero for years before the change point and one for years after the change point.

For each of the possible change points an F-statistic was calculated to measure the magnitude of the change, i.e. $F = t^2 = \{b/SE(b)\}^2$, where b is the estimated step change parameter. Also, the maximum of these statistics, F_{max}, was calculated for all data sets. The significance of the F and F_{max} values for the observed data were then estimated as the proportions of the corresponding values from the null model that equaled or exceeded these observed values.

The bootstrap resampling of residuals requires some further explanation. For a log-linear model where some of the counts are small the distribution of residuals varies to some extent with the expected count. This is because the distribution of residuals should be approximately normally distributed for observations with large expected counts, but will be positively skewed for observations with low expected counts. This comes about because negative counts cannot occur. Therefore, if for example the expected value of a count is 0.5 then a 0 observed count gives a residual (observed - expected) of -0.5, which is the only negative value possible. However, observed counts of 1, 2, 3, etc. give positive residuals of 0.5, 1.5, 2.5, etc. Hence the negative residuals are bounded, but the positive residuals are not.

This problem also occurs with Pearson residuals, which are what was resampled to generate null model data for the Monte Carlo tests. The ith Pearson residual is

$$R_i = \{Y_i - E(Y_i)\}/\sqrt{\{E(Y_i)\}},$$

where Y_i is the ith observed count, with expected value $E(Y_i)$ from the model estimated from the real data. Therefore if $E(Y_i) = 0.5$ then observed counts of 0, 1, 2, 3, ... give Pearson residuals of -0.71, 0.71, 2.12, 3.54, ...

To overcome this problem, residuals were resampled in five groups corresponding to the expected counts. For example, Figure 1 shows the residuals from the log-linear model for splittail from the FMWT. Here there are 497 counts being modeled. The smallest 99 expected counts provide the first group of residuals, of which only one is not zero. The next largest 99 expected counts provide the second group of residuals, with seven of these being positive and some being slightly negative, and so on. The distributions of residuals are distinctly different for the different groups. In general, the size of the first four groups is the integer part of the total number of observations divided by five, with the last group (with the largest expected counts) containing the remaining residuals.

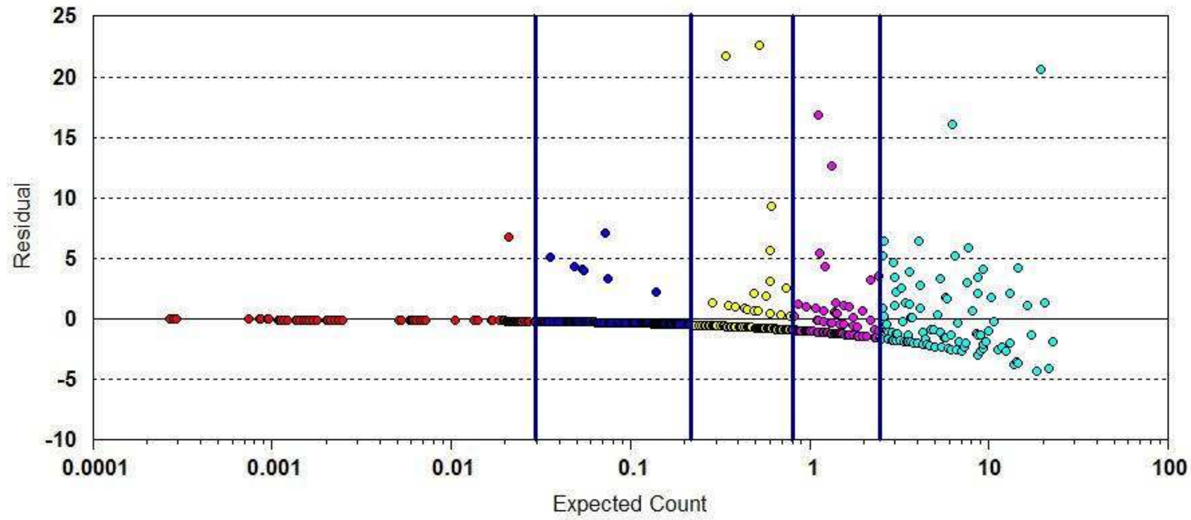

Figure 1 Pearson residuals plotted against expected counts from a log-linear model for splittail counts from the FMWT. The Pearson residuals are divided into five groups as shown for bootstrap resampling.

Bootstrapping resampling worked as follows. First, the Pearson residuals R_1, R_2, ..., R_n were calculated from the model estimated using the real data. These residuals were then divided into five groups based on the size of E(Y), as explained above. The ith observed count for a bootstrap set of data was then generated by selecting at random a residual from the residual group corresponding to the magnitude of the expected value $E(Y_i)$. Assume that this residual is R^*_i. Then this was made the true Pearson residual by setting

$$R^*_i = \{Y^*_i - E(Y_i)\}/\sqrt{\{E(Y_i)\}},$$

where Y_i^* is the bootstrap count. Solving this equation for the observed count gives

$$Y^*_i = E(Y_i) + R^*_i \sqrt{\{E(Y_i)\}}.$$

As the observed count must be zero or a positive integer, Y^*_i was then replaced by the maximum of zero or the integer part of $Y^*_i + 0.5$. The bootstrap set of data was then exactly the same as the original set of data except that the observed counts were set equal to these new bootstrap counts.

As the Monte Carlo method just described is not standard, a special program had to be written to carry out the calculations. This always produced the same estimates and standard errors as GenStat so that the estimation procedure is reliable. The full analysis was also tested on a set of simulated data based on the log-linear model for striped bass age 0 with the FMWT. The log-linear model in this case used the 43 estimated parameters obtained from the real data, but counts were generated from a Poisson distribution with a heterogeneity factor of ten. This data generation was done directly and not using the bootstrap method described above. The data had no step changes.

The bootstrap analysis was run on the generated data, with 1000 resamples. The mean estimated heterogeneity factor was 9.18, and probabilities for the observed step changes ranged from 0.092 to 0.984. This seems exactly the type of result expected if the null model is correct with no step changes.

Results for the Fall Midwater Trawl Samples

Table 1 summarizes the results from the Monte Carlo model applied to the counts from the FMWT. The following points can be noted from this table.

(a) The simulations indicate that the p-values determined for the 2001-02 step change parameters using the usual theory for log-linear models are generally too small. For example, for white sturgeon the p-value provided by the usual analysis is 0.009 but the Monte Carlo model suggests that a more realistic value is 0.083, which is no longer significant at the 5% level. The problem with the usual analysis is presumably due to large numbers of zero counts making the standard theory unreliable.

(b) When an allowance is made for multiple testing there are many change points with significant results. For example, for longfin smelt there are nine points where the estimated change parameter is significant, after allowing for multiple testing. This suggests that, at least for some of the fish, a model with smooth changes in the mean abundance is not appropriate. Rather, it seems that abrupt changes may be quite common.

(c) Although there are these many significant changes even after allowing for multiple testing, there are only two cases where a significant change is between 2001 and 2002, for American shad and threadfin shad. Furthermore, it is only for threadfin shad that the 2001-02 change is the most significant of all the estimated changes.

Overall this analysis gives little support for the hypothesis that the changes in fish abundance between 2001 and 2002 are the result of a step change in the ecosystem that is unusual in comparison with the usual changes in the system.

Table 1 Results of change point tests for fish counts from Fall Midwater Trawl sampling, 1967-2004.

Species	Estimated Change 2001-2 b[1]	Estimated Change 2001-2 P-Value[2]	Monte Carlo P-Value[3]	Critical F-Value[4]	Years Showing Significant Changes Allowing for Multiple Testing[5]
American Shad	1.74	<0.001	<0.001	25.28	1982-83 1983-84 1992-93 1998-99 2001-02 2002-03
Chinook Salmon	-1.31	0.003	0.018	19.36	1987-88
Delta Smelt	-1.38	0.002	0.104	41.92	1978-80
Longfin Smelt	-5.84	<0.001	<0.001	39.76	1977-78 1978-80 1982-83 1983-84 1984-85 1992-93 1993-94 1994-95 1997-98 2000-01
Splittail	-2.27	<0.001	0.031	39.99	1983-84 1986-87 1987-88 1994-95 1996-97 1997-98 1999-00
Striped Bass Age 0	-3.00	0.001	0.007	22.75	1967-68 1968-69 1980-81 1981-82 1984-85 1986-87 1987-88
Striped Bass Age 1	-0.76	0.066	0.179	32.27	1996-97 1997-98
Threadfin Shad	-2.69	<0.001	<0.001	48.11	1976-77 1996-97 2001-02
White Catfish	2.27	0.006	0.060	58.42	
White Sturgeon	-2.21	0.009	0.083	22.86	1984-85 1986-87 1994-95 1995-96

[1]The estimated step change parameter (b), such that exp(b) is the estimated change in the mean abundance of the species.

[2]The p-value from the log-linear model fit, based on standard theory

[3]The p-value from the bootstrap simulation model.

[4]The critical F-value for testing the significance of estimated change points allowing for multiple testing. For each set of simulated data a change parameter was estimated for all possible change points, and the maximum of the corresponding F-values, $\{b/SE(b)\}^2$ was determined. The critical F-values shown are then the values equaled or exceeded for 5% of the simulated sets of data. If the F-value for an estimated step change parameter exceeds this value then it is significantly large because the probability of such a large value occurring for any possible change point in the series is 0.05 or less.

[5]The points where estimated step changes have F-values as large or larger than the 5% critical value allowing for multiple testing. The underlined times are the ones for which the step change is most significant. No data are available for 1974 and 1979.

Table 2 Results of change point tests for fish counts from otter trawl and midwater trawls for the Bay Study, 1980-2004.

Species		Estimated Change b[1]	2001-2 P-Value[2]	Monte Carlo P-Value[3]	Critical F-Value[4]	Years Showing Significant Changes Allowing for Multiple Testing[5]				
American Shad	MWT	0.50	0.011	0.243	40.10	1981-82	1983-84	1997-98	<u>2002-03</u>	
Chinook Salmon	MWT	-0.57	0.001	0.051	26.09					
Threadfin Shad	MWT	-1.23	<0.001	0.122	43.12	1997-98	<u>2000-01</u>			
Longfin Smelt age 0	OT	2.50	<0.001	0.043	51.72	<u>1981-82</u>	1982-83	1994-95	<u>1995-96</u>	
Pacific Staghorn Sculpin age 0	OT	0.58	0.008	0.209	49.83					
Starry Flounder age 0	OT	1.24	<0.001	0.055	34.64	<u>1981-82</u>	1994-95	1999-00	2002-03	
Striped Bass age 0	OT	-1.45	<0.001	0.022	41.88					
Yellow Gobi age 0	OT	-1.34	0.019	0.204	42.99	1986-87	1991-92	<u>1992-93</u>	1993-94	1995-96

[1]The estimated step change parameter (b), such that exp(b) is the estimated change in the mean abundance of the species.

[2]The p-value from the log-linear model fit, based on standard theory

[3]The p-value from the bootstrap simulation model.

[4]The critical F-value for testing the significance of estimated change points allowing for multiple testing. For each set of simulated data a change parameter was estimated for all possible change points, and the maximum of the corresponding F-values, $\{b/SE(b)\}^2$ was determined. The critical F-values shown are then the values equaled or exceeded for 5% of the simulated sets of data. If the F-value for an estimated step change parameter exceeds this value then it is significantly large because the probability of such a large value occurring for any possible change point in the series is 0.05 or less.

[5]The points where estimated step changes have F-values as large or larger than the 5% critical value allowing for multiple testing. The underlined times are the ones for which the step change is most significant.

Results for the Bay Study Samples

For the Bay Study midwater and otter trawls an analysis is only provided for the fish counts where the estimated change point parameter for 2001-02 is significant at the 5% level from the standard log-linear model analysis. This is because the p-value from the Monte Carlo analysis is expected to be considerably larger than the one from the standard log-linear model. Hence if a change parameter is not significant for the standard model it will certainly not be for the Monte Carlo analysis.

Table 2 gives a summary of the results of the Monte Carlo analyses. As was the case for the FMWT data, the p-values for the estimated step change parameters are much higher from the Monte Carlo analysis than they were from the standard analysis. For example, the p-value for American shad is 0.011 from the standard analysis, but 0.243 from the Monte Carlo model. As a result, only two 2001-02 step change parameters are significant at the 5% level based on the Monte Carlo model (for longfin smelt age 0 and striped bass age 0), although two other parameters are close (for chinook salmon and starry flounder age 0).

None of the 2001-02 step change parameters is significant at the 5% level when there is an allowance for multiple testing. However, this more stringent test of significance does give significant results for five of the eight fish counts. For example, American shad had significant changes for 1981-82, 1983-84, 1997-98 and 2002-03, with the last of these changes being the most significant one. Hence, as was the case for the FMWT data, it does seem that step changes have occurred at various time for some of the fish being sampled. Or, at any rate, the Monte Carlo null model of smooth trends in the underlying abundance of the fish with superimposed random fluctuations from year to year is not appropriate for at least some of the fish.

Conclusion

The analyses reported here provide little evidence that the apparent step changes in abundance between 2001 and 2002 are unusual in comparison with apparent changes at other times. Significant step changes are observed for some fish counts, even in comparison with the distribution of the maximum estimated change observed at any time for a null model without any step changes. Step changes therefore do seem to occur. However, there is only one case where the most significant change is between 2001 and 2002.

References

Manly, B.F.J. (2001). *Statistics for Environmental Science and Management*. Chapman and Hall/CRC, Boca Raton.

Manly, B.F.J. (2005a). *Analyses A: Log-Linear Modeling, Linear Regression, and Principal Components Analysis for Fall Midwater Trawl Fish Counts, 1967-2004*. Report prepared for the Interagency Ecological Program, California, by Western EcoSystems Technology, Inc.

Manly, B.F.J. (2005b). *Analyses B: Log-Linear Modeling, Linear Regression, and Principal Components Analysis for Midwater Trawl and Otter Trawl Fish Counts 1980-2004 from the Bay Study*. Report prepared for the Interagency Ecological Program, California, by Western EcoSystems Technology, Inc.

Solow, A. and Beet, A.R. (2005). A test for a regime shift. *Fisheries Oceanography* 14: 236-240.

Effects of Hydrological, Environmental and Other Variables on Delta Smelt Counts

Bryan F. J. Manly
Western EcoSystems Technology Inc.
Cheyenne, Wyoming
bmanly@west-inc.com

Summary 2

Introduction 4

The Data 4

Log-Linear Modeling 9

Bootstrap Analysis 14

Further Modifications to the Model 19

Discussion 25

References 25

Summary

- This report concerns the analysis of the numbers of delta smelt obtained from the fall midwater trawl (FMWT) sampling in 14 geographical areas in the years 1967 to 2004, except there was no sampling in 1974 and 1979. The dependent variable considered is the count of delta smelt from all trawls in one area in one year, although all areas were not sampled in every year. Log-linear modeling is used to relate the delta smelt counts to a hydrological and environmental variables, with an allowance for a time trend and step changes in numbers, particularly a step change between 2001 and 2002.

- There are six basic hydrological variables (Sacramento River flow, the number of Yolo bypass flooding days, the San Joaquin River flow, the export/inflow ratio, the total exports/San Joaquin River flow ratio, and total exports). Each of these variables is measured in two or more ways. For example the Sacramento River flow is measured in four ways based on different averaging periods. The environmental variables are the water temperature, the conductivity at the to of the water column, and the Secchi distance. The hydrological variables and conductivity were scaled to have maximums of one over the full data set.

- Plots of the catch per unit effort (CPUE, catch per trawl) against the hydrological variables indicate various relationships, apparently non-linear in some cases. Correlation coefficients between variables show high positive and negative correlations, particularly between some hydrological variables.

- In order to choose which way to measure the hydrological variables a basic log-linear model with effects for the sampling areas and a quartic time trend was considered. The six basic hydrological variables were then investigated one at a time. For example, the four ways to measure the Sacramento River flow were denoted by Sac1, Sac2, Sac3 and Sac4. The fit of the basic log-linear model plus Sac1 and $Sac1^2$ was then compared with the fit of the basic model plus Sac2 and $Sac2^2$, the fit of the basic model plus Sac3 and $Sac3^2$, and the fit of the basic model plus Sac4 and $Sac4^2$. It was found that Sac1 and $Sac1^2$ gave the best fit so the other measures of the Sacramento River flow were not considered further. A similar approach was also used to select the method for measuring the other hydrological variables.

- All of the chosen hydrological variables were added into the equation, together with temperature, conductivity and Secchi, with quadratic effects considered. Non-significant effects were then removed, resulting in an equation with 13 estimated coefficients for hydrological and environmental effects. At that point a step effect between 2001 and 2002 was added into the model and found to be significant by the usual t-test.

- A bootstrap analysis was carried out to assess the validity of the fitted model. This indicated that the significance of estimated coefficients tends to be exaggerated to some extent using standard t-tests, and that some terms for hydrological effects should therefore be removed from the model. In addition, the step effect for 2001-02 is not at all significant, particularly taking into account the possibility of step effects between all pairs of successive years. However, step effects for 1981-82 and 1998-99 are significant and apparently should be included in the fitted model.

- The model was modified based on the bootstrap analysis, and another bootstrap analysis was run to check that the modified model is reasonable. This was the case. This model includes estimated effects for the area, time trends, the Sacramento River flow, the number of Yolo bypass flooding days, the export/inflow ratio, the total exports/San Joaquin River flow ratio, total exports, the Secchi distance, conductivity, and step changes for 1981-82 and 1998-99.

- The nature of the effects included in the final model is discussed, noting that they represent past associations between the delta smelt abundance that are not necessarily causal relationships, and association may be affected in various ways by the high positive and negative correlations between some of the hydrological variables.

Introduction

This report describes the analysis of the fall midwater trawl (FMWT) catches of delta smelt for the years 1967 to 2004, taking into account the values of various hydrological and environmental variables. A similar type of analysis is also possible on other species caught in reasonable numbers in the FMWT. Log-linear models were used to describe the data, with bootstrap analyses used to assess the validity of fitted models.

The Data

The dependent variable analyzed is the count of delta smelt in samples from all samples in one area of the Sacramento-San Joaquin Delta in one year. A total of 110 sampling stations in 14 geographical areas were sampled, as indicated in Figure 1. The sampling stations were not always sampled every year, and in some years some of the geographical areas were not sampled. No sampling was carried out in 1974 and 1979. The fish counts are provided in Appendix A of Manly (2005a). There are 496 counts available.

Figure 1 The sampled areas for fall midwater trawls in the Sacramento-San Joaquin Delta. Areas numbered 2, 6 and 9 were not sampled and are not shown in the figure.

There are three variables associated with the local conditions during sampling that can be used to account for some of the variation in the catch. These are the temperature of the water (Temp, °C), the Secchi reading of water clarity (Secchi), and the conductivity (CondTp, units?) at the top of the water column, which is a measure of the salinity of the water (?). For the analysis the average values of these variables for the yearly catches in an area were used. Because of the large values for CondTp, the values for this variable were scaled to have a maximum of one. This resulted in a range from 0.00 to 1.00 for the scaled values.

A number of large scale hydrological variables are also available on a yearly basis, or associated with certain parts of the year. These are as follows.

Sac1	The January to September average Sacramento river flow, scaled to have a maximum of one, which gives an observed range from 0.15 to 1.00.
Sac2	The January to March average Sacramento river flow, scaled to have a maximum of one, which gives an observed range from 0.12 to 1.00.
Sac3	The April to June average Sacramento river flow, scaled to have a maximum of one, which gives an observed range from 0.12 to 1.00.
Sac4	The June to September average Sacramento river flow, scaled to have a maximum of one, which gives an observed range from 0.22 to 1.00.
Yolo1	The number of Yolo bypass flooding days, when the Sacramento River flow exceeded 55,000 cfs for December in the previous year to June inclusive, scaled to a maximum of one, which gives a range from 0.00 to 1.00.
Yolo2	The number of Yolo bypass flooding days, when the Sacramento River flow exceeded 55,000 cfs for March to May inclusive, scaled to a maximum of one, which gives a range from 0.00 to 1.00.
SJR1	The January to September average San Joaquin River flow, scaled to have a maximum of one, which gives an observed range from 0.02 to 1.00.
SJR2	The average of the San Joaquin River flows below the median for February to May, scaled to have a maximum of one, which gives an observed range from 0.01 to 1.00.
SJR3	The average of the San Joaquin River flows above the median for February to May, scaled to have a maximum of one, which gives an observed range from 0.02 to 1.00.
SJR4	The June to September average San Joaquin River flow, scaled to have a maximum of one, which gives an observed range from 0.01 to 1.00.
ExIn1	The average of the exports/Inflow ratio for February to May, scaled to have a maximum of one, which gives an observed range from 0.04 to 1.00.
ExpIn2	The average of the total exports/Inflow ratios above the median for February to May, scaled to have a maximum of one, which gives an observed range from 0.05 to 1.00.

ExpSJR1 The average of the total exports/San Joaquin River flow ratio from February to May, scaled to have a maximum of one, which gives an observed range from 0.02 to 1.00.

ExpSJR2 The average of the upper quartile of the total exports/San Joaquin River flow ratio from February to May, scaled to have a maximum of one, which gives an observed range from 0.02 to 1.00.

TExp1 The average of the total exports from February to April, scaled to have a maximum of one, which gives an observed range from 0.13 to 1.00.

TExp2 The average of the total exports from May to September, scaled to have a maximum of one, which gives an observed range from 0.17 to 1.00.

For an initial exploration of the data the delta smelt catches were converted to catch per unit effort values (CPUE, the average number of delta smelt per trawl) and plotted against all of the variables described above. The result is shown in Figure 2. In this figure the trend lines shown are from a locally weighted robust regression smooth (loess), which is intended to represent the general changes in the data without assuming any particular function for those changes.

The plots suggest a downward trend in numbers in the first half of the sampled period, most delta smelt found in the higher numbered sampling areas (to the east, Figure 1), and most catches associated with temperatures from about 12° to 18°, low Secchi numbers, and low conductivity. In terms of the hydrological variables there are suggestions of some non-linear relationships, with the highest CPUE values (greater than 10) associated with low to moderate Sac1, all values of Sac2, low to moderate values of Sac3 and Sac4, low to moderate values of Yolo1, low values of Yolo2, low to moderate values of SJR1 to SJR4, moderate values of ExpIn1 and ExpIn2, low to fairly high values of ExpSJR1 and ExpSJR2, low to moderate values of TExp1, and moderate values of TExp2.

Because of the similarity between many of the hydrological variables it is expected that there will be some high correlations between them. Table 1 shows that this is the case. The delta smelt variable DSm is the CPUE. This is significantly negatively correlated only with temperature, Secchi, top conductivity, ExpIn1 and TExp, and significantly positively correlated with Sac2. Temperature is only significantly correlated with Secchi. There are high correlations between the hydrological variables other than TExp2, which shows several non-significant correlations.

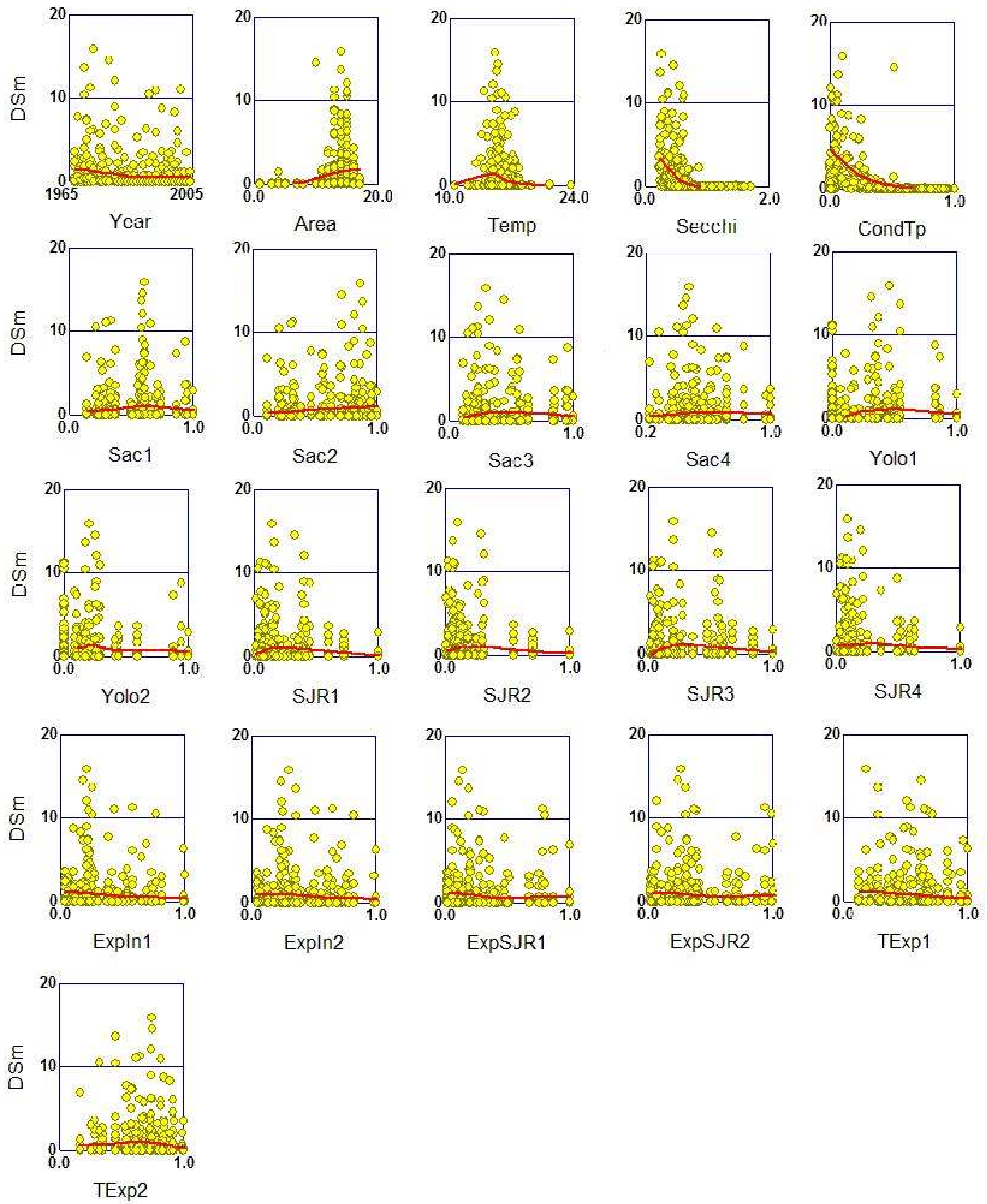

Figure 2 Plots of the delta smelt average catch per trawl (DSm) against the variables described in the text.

Table 1 Correlations between variables. Correlations that are significantly different from zero at the 5% level are in bold text. DSm is the delta smelt CPUE (the average catch per two). There are 497 observations and significance at the 5% level requires a the absolute value of the correlation to exceed 0.088.

	DSm	Temp	Secchi	CondTp	Sac1	Sac2	Sac3	Sac4	Yolo1	Yolo2	SJR1	SJR2	SJR3	SJR4	ExpIn1	ExpIn2	ExpSJR1	ExpSJR2	TExp1	TExp2
DSm	1.00	**-0.13**	**-0.32**	**-0.40**	0.07	**0.11**	0.01	0.02	0.07	0.02	-0.01	-0.02	0.01	-0.03	**-0.09**	-0.09	-0.06	-0.05	**-0.11**	-0.02
Temp	**-0.13**	1.00	**0.17**	0.02	-0.02	-0.01	-0.03	0.01	0.02	0.01	0.03	0.00	0.03	-0.00	0.00	0.00	0.02	-0.00	0.03	0.08
Secchi	**-0.32**	**0.17**	1.00	**0.37**	**-0.32**	**-0.31**	**-0.28**	**-0.28**	**-0.30**	**-0.27**	**-0.25**	**-0.23**	**-0.27**	**-0.23**	**0.31**	**0.29**	**0.33**	**0.30**	**0.10**	-0.06
CondTp	**-0.40**	0.02	**0.37**	1.00	**-0.26**	**-0.24**	**-0.24**	**-0.25**	**-0.25**	**-0.22**	**-0.23**	**-0.21**	**-0.22**	**-0.23**	**0.23**	**0.25**	**0.23**	**0.24**	**0.14**	0.01
Sac1	0.07	-0.02	**-0.32**	**-0.26**	1.00	**0.94**	**0.91**	**0.91**	**0.95**	**0.87**	**0.80**	**0.74**	**0.81**	**0.79**	**-0.84**	**-0.87**	**-0.78**	**-0.78**	**-0.27**	**0.23**
Sac2	**0.11**	-0.01	**-0.31**	**-0.24**	**0.94**	1.00	**0.72**	**0.75**	**0.92**	**0.75**	**0.75**	**0.67**	**0.80**	**0.64**	**-0.87**	**-0.87**	**-0.83**	**-0.79**	**-0.33**	**0.27**
Sac3	0.01	-0.03	**-0.28**	**-0.24**	**0.91**	**0.72**	1.00	**0.93**	**0.84**	**0.88**	**0.75**	**0.73**	**0.71**	**0.85**	**-0.69**	**-0.74**	**-0.60**	**-0.63**	**-0.19**	0.07
Sac4	0.02	0.01	**-0.28**	**-0.25**	**0.91**	**0.75**	**0.93**	1.00	**0.83**	**0.79**	**0.72**	**0.69**	**0.67**	**0.79**	**-0.70**	**-0.74**	**-0.63**	**-0.67**	**-0.19**	**0.27**
Yolo1	0.07	0.02	**-0.30**	**-0.25**	**0.95**	**0.92**	**0.84**	**0.83**	1.00	**0.87**	**0.82**	**0.73**	**0.83**	**0.78**	**-0.78**	**-0.81**	**-0.74**	**-0.74**	**-0.32**	**0.11**
Yolo2	0.02	0.01	**-0.27**	**-0.22**	**0.87**	**0.75**	**0.88**	**0.79**	**0.87**	1.00	**0.73**	**0.70**	**0.73**	**0.80**	**-0.65**	**-0.69**	**-0.58**	**-0.58**	**-0.11**	**0.11**
SJR1	-0.01	0.03	**-0.25**	**-0.23**	**0.80**	**0.75**	**0.75**	**0.72**	**0.82**	**0.73**	1.00	**0.96**	**0.97**	**0.94**	**-0.65**	**-0.70**	**-0.68**	**-0.72**	**-0.29**	-0.03
SJR2	-0.02	0.00	**-0.23**	**-0.21**	**0.74**	**0.67**	**0.73**	**0.69**	**0.73**	**0.70**	**0.96**	1.00	**0.91**	**0.94**	**-0.59**	**-0.64**	**-0.59**	**-0.63**	**-0.22**	-0.05
SJR3	0.01	0.03	**-0.27**	**-0.22**	**0.81**	**0.80**	**0.71**	**0.67**	**0.83**	**0.73**	**0.97**	**0.91**	1.00	**0.87**	**-0.70**	**-0.74**	**-0.73**	**-0.75**	**-0.31**	0.02
SJR4	-0.03	-0.00	**-0.23**	**-0.23**	**0.79**	**0.64**	**0.85**	**0.79**	**0.78**	**0.80**	**0.94**	**0.94**	**0.87**	1.00	**-0.59**	**-0.64**	**-0.59**	**-0.63**	**-0.25**	**-0.10**
ExpIn1	**-0.09**	0.00	**0.31**	**0.23**	**-0.84**	**-0.87**	**-0.69**	**-0.70**	**-0.78**	**-0.65**	**-0.65**	**-0.59**	**-0.70**	**-0.59**	1.00	**0.99**	**0.88**	**0.82**	**0.52**	**-0.10**
ExpIn2	-0.09	0.00	**0.29**	**0.25**	**-0.87**	**-0.87**	**-0.74**	**-0.74**	**-0.81**	**-0.69**	**-0.70**	**-0.64**	**-0.74**	**-0.64**	**0.99**	1.00	**0.89**	**0.86**	**0.51**	**-0.09**
ExpSJR1	-0.06	0.02	**0.33**	**0.23**	**-0.78**	**-0.83**	**-0.60**	**-0.63**	**-0.74**	**-0.58**	**-0.68**	**-0.59**	**-0.73**	**-0.59**	**0.88**	**0.89**	1.00	**0.97**	**0.41**	**-0.25**
ExpSJR2	-0.05	-0.00	**0.30**	**0.24**	**-0.78**	**-0.79**	**-0.63**	**-0.67**	**-0.74**	**-0.58**	**-0.72**	**-0.63**	**-0.75**	**-0.63**	**0.82**	**0.86**	**0.97**	1.00	**0.39**	**-0.27**
TExp1	**-0.11**	0.03	**0.10**	**0.14**	**-0.27**	**-0.33**	**-0.19**	**-0.19**	**-0.32**	**-0.11**	**-0.29**	**-0.22**	**-0.31**	**-0.25**	**0.52**	**0.51**	**0.41**	**0.39**	1.00	**0.35**
TExp2	-0.02	0.08	-0.06	0.01	**0.23**	**0.27**	0.07	**0.27**	**0.11**	**0.11**	-0.03	-0.05	0.02	**-0.10**	**-0.10**	**-0.09**	**-0.25**	**-0.27**	**0.35**	1.00

Log-Linear Modeling

Log-linear models were fitted to the data. These models are of the form

$$E(Y) = W.\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p), \qquad (1)$$

where E(Y) is the expected value of the number of delta smelt captured in W trawls, β_0 to β_p are unknown parameters to be estimated, and X_1 to X_p are variables to account for differences between the sampling areas, trend in time, and some or all of the environmental and hydrological variables described above. Following standard practice, the actual counts are assumed to follow a Poisson distribution, but with an inflated variance. The inflation factor, which is also called the heterogeneity factor or the dispersion parameter, is then estimated as part of the analysis.

The hydrological variables come in groups and it was decided that at most one variable would be included in the model from each group. For example the Sacramento River flow is measured by Sac1 to Sac4, so only one of these variables was allowed in the model. Also, Figure 1 suggests that some of the relationships with hydrological variables may be non-linear. Therefore quadratic terms as well as linear terms were considered for each of the hydrological variables.

What was done was to first fit a model allowing the constant term in equation (1) to vary with the sampling area and allowing for quartic time trends. This gave an extremely significant fit to the data ($F = 46.39$ with 17 and 479 df, $p < 0.001$), with some significant to very highly significant parameter estimates. It was therefore considered to be a reasonable base model for the addition of extra effects.

The groups of hydrological variables were then considered one by one, taking Sac1 to Sac4 first. The fit of models including Sac1 and Sac1^2, Sac2 and Sac2^2, Sac3 and Sac3^2, and Sac4 and Sac4^2 was compared, and the best fitting variable chosen for use in the model. It was found that Sac1 and Sac1^2 gave the best fit, so the other Sac variables were not considered further.

Following this procedure with all of the groups of hydrological variables led to linear and quadratic terms of Sac1, Yolo1, SJR3, ExpIn1, ExpSJR1 and TExp2 being chosen for entry into the model. Adding all of these terms into the equation resulted in a very significant fit to the data ($F = 34.33$ with 29 and 467 df, $p < 0.001$), with a significant improvement on the model without these terms ($F = 7.14$ with 12 and 467 df, $p < 0.001$).

At that stage the temperature, Secchi and top conductivity variables were added into the equation, giving another substantial and very significant improvement in fit ($F = 36.09$ with 3 and 464 df, $p < 0.001$).

It was then considered that possibly the effects of temperature Secchi and top conductivity might be non-linear, so the $Temp^2$, $Secchi^2$ and $CondTp^2$ were added into the model. However, as the coefficients of $Temp^2$, $Secchi^2$ were not significantly different from zero these were subsequently removed. The linear effect of temperature was also not significant so this was then also removed. Other effects with coefficients that were not significantly different from zero ($Sac1^2$ and $SJR3^2$) were also removed at this time.

Finally, the possibility of a step change in the population between 2001 and 2002 was allowed for by including an indicator variable in the model which was equal to 0 for observations up to including 2001 and equal to 1 for observations in 2002 to 2004. This gave a highly significant improvement to the model ($F = 6.94$ with 1 and 464 df, $p = 0.009$). The estimated coefficient of the indicator variable is -1.072 (standard error = 0.421), suggesting that between 2001 and 2002 the population size was multiplied by exp(-1.072) = 0.342, i.e. there was a 66% drop in numbers. All of the estimates from the final model including the step change effect are provided in Table 2.

The hydrological and environmental effects estimated in the model are non-linear in the sense that they all represent multiplicative effects on the expected number of delta smelt. For example, consider the estimated effect for Yolo1. For this effect the equation has a coefficient of 3.383 for Yolo1 and -5.538 for $Yolo1^2$. This means that for a given value of Yolo1 the expected number of delta smelt is multiplied by $\exp(3.383Yolo1 - 5.538Yolo1^2)$. This equals $\exp(0.0) = 1.0$ when Yolo1 = 0, $\exp(-2.155) = 0.12$ when Yolo1 = 1, and a maximum of $\exp(0.517) = 1.68$ when Yolo1 = 0.305. The estimated multiplicative effects for this and the other effects in the model are illustrated in Figure 3 for the ranges covered in the data.

The multiplicative effects of the hydrological and environmental variables are assumed to be the same in all of the sampling areas and all of the years. The estimated effects over time can therefore be illustrated by considering one area only. For this purpose area 15 was chosen because it is one of the areas with relatively high delta smelt numbers (Figure 1). Figure 4 shows the observed and expected CPUE for delta smelt, and the estimated effects that make up the expected values. The way this works is that the expected CPUE for each year is the product of all of the other effects shown in the figure for the same year, some high and some low. Here the area effect comes from the constant in the equation (-5.55) and the area 15 effect (2.59). The multiplicative effect in this case is therefore $\exp(-5.55 + 2.59) = 0.052$.

It is interesting to note how the various effects combine. For example, consider the year 1983, which had the lowest observed and the lowest expected CPUE. For that year the Sacramento River flow and total export effects were relatively high, but the exports to inflow, Yolo bypass flooding and San Joaquim River effects were relatively low. It was the outcome of all of these effects that was a very low expected CPUE.

Table 2 Estimates of parameters for the final fitted log-linear model for delta smelt catch numbers.

Parameter	Estimate	SE	t-Value[a]	P-Value
Constant	-5.30502	1.84662	-2.87	0.004
Area 3[b]	1.60439	2.47747	0.65	0.518
Area 4	2.36153	1.77227	1.33	0.183
Area 5	1.60471	1.99596	0.80	0.422
Area 7	0.85669	4.59140	0.19	0.852
Area 8	-0.31298	9.93531	-0.03	0.975
Area 10	2.73344	1.58075	1.73	0.084
Area 11	0.57988	1.53088	0.38	0.705
Area 12	1.08831	1.49416	0.73	0.467
Area 13	1.92795	1.49546	1.29	0.198
Area 14	1.96215	1.49452	1.31	0.190
Area 15	2.59396	1.51702	1.71	0.088
Area 16	1.19146	1.52509	0.78	0.435
Area 17	-0.58942	1.58843	-0.37	0.711
T1[c]	0.04893	0.01608	3.04	0.002
T2	0.00676	0.00186	3.64	0.000
T3	-0.00010	0.00008	-1.27	0.205
T4	-0.00002	0.00001	-3.09	0.002
Sac1	5.24264	1.45618	3.60	0.000
Yolo1	3.65487	0.86747	4.21	0.000
$Yolo1^2$	-5.68327	0.79506	-7.15	0.000
SJR3	-1.14296	0.42851	-2.67	0.008
ExpIn1	8.24348	2.47722	3.33	0.001
$ExpIn1^2$	-6.03527	1.58612	-3.81	0.000
ExpSJR1	-2.71418	1.93839	-1.40	0.162
$ExpSJR1^2$	3.97846	1.60937	2.47	0.014
TExp2	5.62193	1.69363	3.32	0.001
$TExp2^2$	-5.79042	1.34797	-4.30	0.000
Secchi	-2.77660	0.59438	-4.67	0.000
CondTp	5.40915	1.85501	2.92	0.004
$CondTp^2$	-23.47290	4.32705	-5.42	0.000
Step	-1.15927	0.41791	-2.77	0.006

[a]The t-value is the estimate divided by the standard error(SE) and the P-value is the probability of obtaining a value this far from zero by chance.

[b]The area effects are estimated relative to area 1 for which the estimate is defined to be zero.

[c]T1 to T4 are time effects, where Ti = $(Year - 1986)^i$.

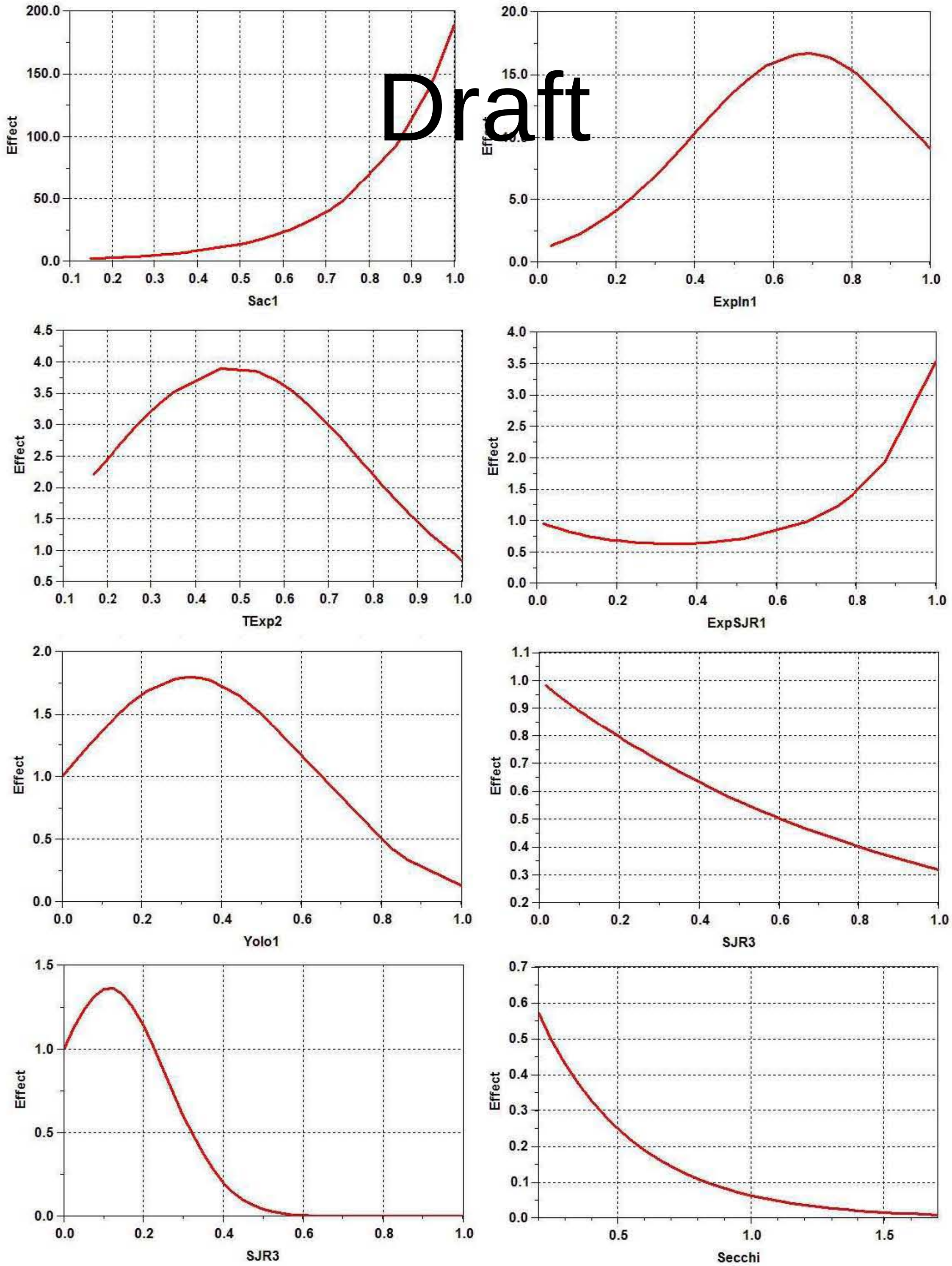

Figure 3 Estimated effects of hydrological and environmental variables in the log-linear model for delta smelt counts.

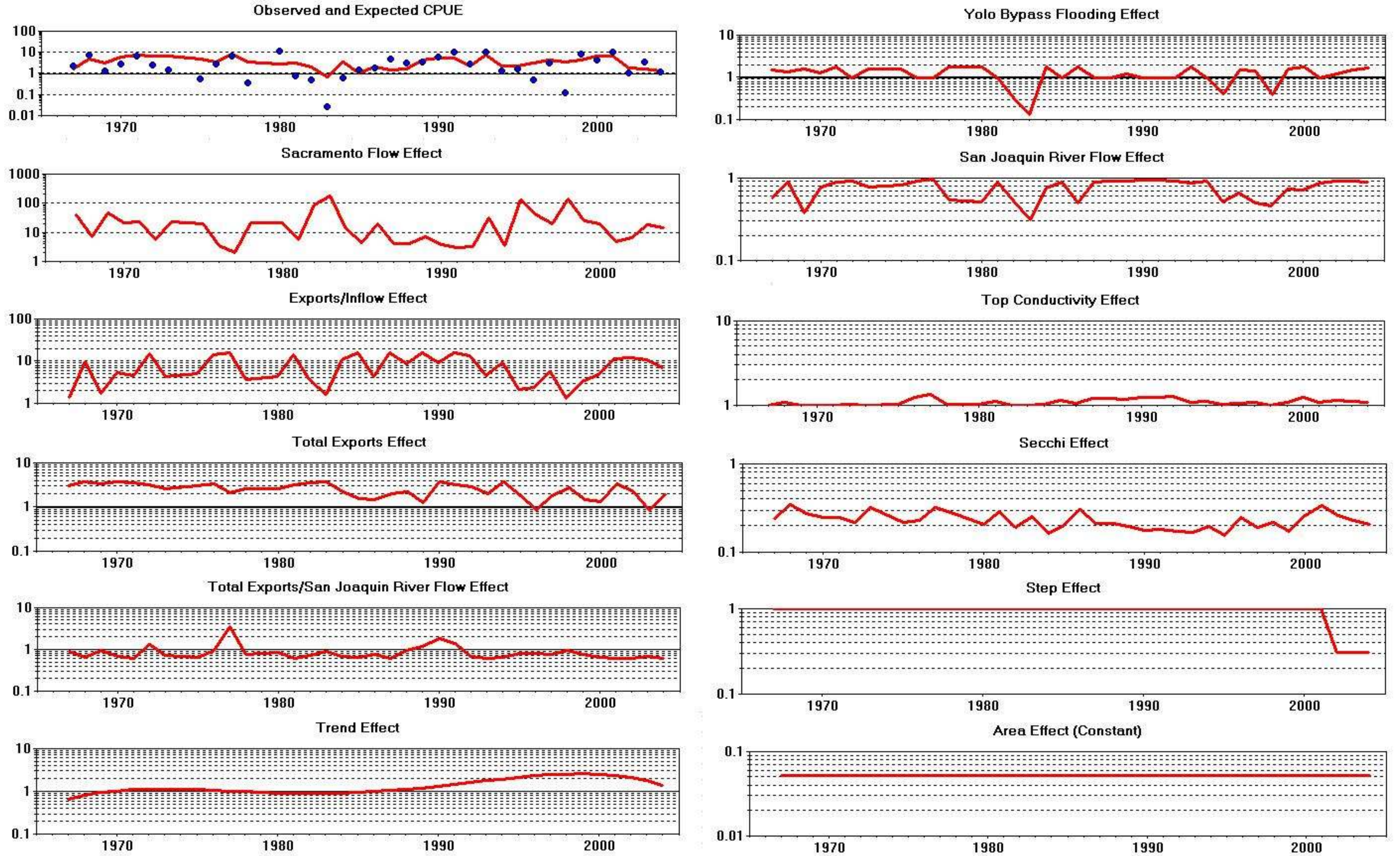

Figure 4 The observed and expected CPUE for delta smelt in area 15, with the multiplicative effects that make up the expected CPUE, i.e., the expected CPUE is found by multiplying together all of the effects for the year being considered.

Figure 5 shows how the observed and expected frequencies compare for all of the data, rather than just area 15. The fit is far from perfect but does show how the observed frequencies tend to increase with the expected frequencies from the model. The plotted line is for equal observed and expected frequencies. The increasing dispersion about this line is expected based on the model being considered which assumes that the variance is proportional to the mean.

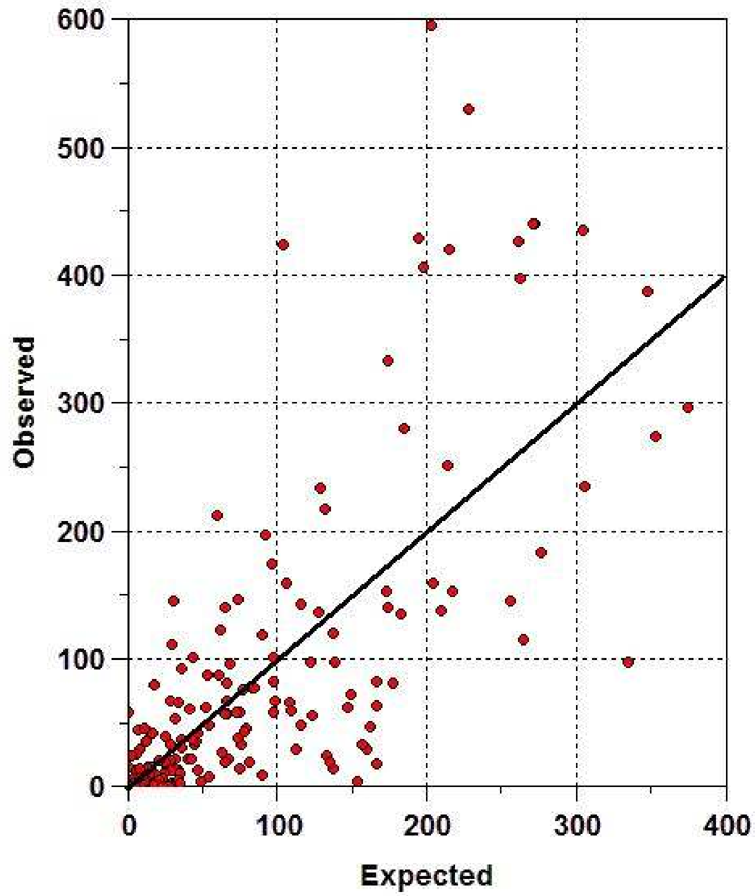

Figure 5 Observed and expected counts of delta smelt for all sampled areas and years.

Bootstrap Analysis

The bootstrap analysis described by Manly (2005b) was applied with the fitted log-linear model for delta smelt. Although there are now hydrological and environmental variables in the model, the method can be used in the same way as before. Briefly, the model described in Table 2 was fitted to the observed data without the change-point indicator variable, but including all the other variables. An estimated change-point effect was then estimated for all possible times of a change, i.e. between all pairs of successive years.

The bootstrap procedure then had two aims. The first was to assess the significance of the step-change effect for each of the possible change points, with particular interest in the one for 2001-2. The second aim was to check the validity of the standard errors obtained for the estimated parameters in the log-linear model because the nature of the data (with many zero counts) is likely to mean that the standard methods used for testing the significance of effects using the t and F distributions is rather approximate.

The fitted log-linear model without any change-point effects was the null model for the bootstrap analysis. The Pearson residuals from this model are calculated as

$$R = (O - E)/\sqrt{E},$$

where O is an observed count and E is the expected count from the fitted model. These residuals were placed into five approximately equal sized groups based on the values of E. Thus the first group had the residuals for the smallest one fifth of fitted values, and so on. As explained by Manly (2005c), the reason for the grouping is the fact that the distribution of residuals changes with the values of E, as shown in Figure 6 for a log-linear model fitted to the counts of splittail from the FMWT sampling.

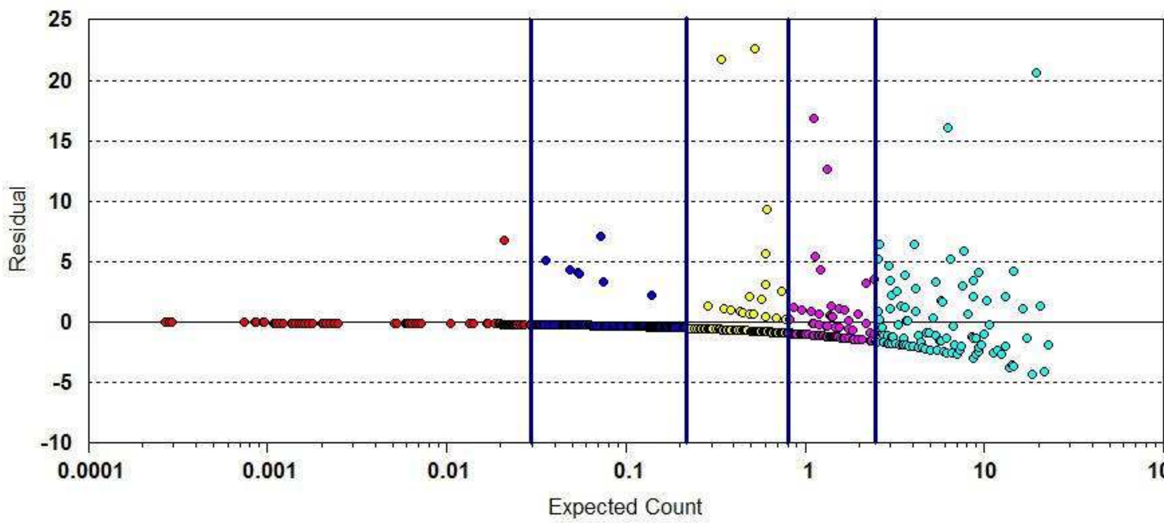

Figure 6 Example of Pearson residuals plotted against expected counts based on a log-linear model for splittail counts from the FMWT. The Pearson residuals are divided into five groups as shown for bootstrap resampling.

A bootstrap set of data was generated by taking the expected values E_1, E_2, ..., E_{497} for each of the 497 observations, based on the null model without any step-change effects. Each of these expected values was then for the total delta smelt count from all tows in a particular sampling area in one year. The expected value E_i falls within one of the five groups based on its magnitude. A residual R_i^B was randomly selected from those for this group to apply for the bootstrap data. This implies that for the bootstrap data the observed count O_i^B corresponding to the expected frequency E_i is given by

$$R_i^B = (O_i^B - E_i)/\sqrt{E_i},$$

so that

$$O_i^B = E_i + R_i^B \sqrt{E_i}.$$

As this will not generally be an integer the bootstrap observed value was then rounded to zero or the nearest positive integer. Applying this procedure with all of the expected frequencies resulted in a bootstrap set of data with the null model true. It was analyzed in exactly the same way as the real data.

One thousand sets of bootstrap data were generated and analyzed in this way. The results were then used to estimate the means and standard errors of the parameters in the null model, and to assess the significance of the estimated step-change effects. The results obtained are summarized in Tables 3 and 4.

The left-hand side Table 3 shows the estimated coefficients for the log-linear model without any step-change effects included, as produced using the usual methods of log-linear modeling. The right-hand side shows the result of generating 1000 sets of data using the parameter estimates on the left-hand side and estimating the parameters for each of these models. The mean of the estimates of a parameter from the 1000 bootstrap sets of data should then be close to the corresponding estimate from the real data, and the standard deviation of the estimates should be close to the corresponding standard error value from the real data. For example, the estimated area 3 parameter for the real data is 1.693 with standard error 2.497 for the real data. The bootstrap mean estimate of the same parameter is 1.585, suggesting that the bias in estimation is approximately 1.585 - 1.693 = -0.108, which is quite small. The bootstrap estimate of the standard error is 2.076, suggesting that, if anything, the standard error estimated in the usual way might be slightly large. Note that the bias here is estimated by the bootstrap mean of the parameter minus the value of the parameter actually used to generate the bootstrap sets of data.

The bootstrap t-values in Table 3 are the values after an adjustment for bias in estimation and using the bootstrap standard error in place of the standard error based on standard theory. For example, for area 3 the t-value based on bootstrapping is

$$t = (1.693 - \text{Bias})/2.076 = (1.693 + 0.108)/2.076 = 0.87,$$

which is just slightly larger than the value of $t = 0.68$ obtained with the original analysis of the data.

Table 3 Estimates of the log-linear model without any step-change parameters included. The estimates on the left are for the log-linear model fitted to the data. The values on the right are the mean and standard errors (SE) of estimates obtained when 1000 bootstrap sets of data were generated using the parameter estimates on the left. The bootstrap values indicate the bias (if any) in estimation, and the standard errors that are actually obtained by the fitting process. The t-values on the right are corrected for any biases in the estimation of a parameter and its standard error.

	Log-linear Model				Bootstrap Values			
Parameter	Estimate	SE	t	Sig[a]	Mean	SE	t	Sig[b]
Constant	-5.30100	1.85400						
Area 3	1.69259	2.49732	0.68	0.498	1.58508	2.07563	0.87	0.386
Area 4	2.35274	1.78668	1.32	0.189	2.26753	1.64854	1.48	0.140
Area 5	1.57971	2.01181	0.79	0.433	1.39698	2.19615	0.80	0.422
Area 7	0.90389	4.70894	0.19	0.848	-2.56857	5.17030	0.85	0.398
Area 8	-6.08301	74.43742	-0.08	0.935	-5.62533	1.82255	-3.59	0.000
Area 10	2.70070	1.59328	1.70	0.091	2.74202	1.49555	1.78	0.076
Area 11	0.56675	1.54304	0.37	0.714	0.65007	1.43725	0.34	0.737
Area 12	1.05304	1.50619	0.70	0.485	1.15740	1.41670	0.67	0.503
Area 13	1.93898	1.50738	1.29	0.199	2.03042	1.41834	1.30	0.193
Area 14	1.92273	1.50646	1.28	0.203	2.02121	1.41468	1.29	0.198
Area 15	2.70753	1.52842	1.77	0.077	2.76555	1.48734	1.78	0.076
Area 16	1.35606	1.53569	0.88	0.378	1.41314	1.50432	0.86	0.388
Area 17	-0.37437	1.59777	-0.23	0.815	-0.15631	1.59606	-0.37	0.711
T1	0.07415	0.01363	5.44	0.000	0.07345	0.02349	3.19	0.002
T2	0.00831	0.00180	4.62	0.000	0.00841	0.00317	2.59	0.010
T3	-0.00027	0.00006	-4.69	0.000	-0.00027	0.00010	-2.80	0.005
T4	-0.00003	0.00001	-5.00	0.000	-0.00003	0.00001	-2.93	0.004
Sac1	5.37887	1.45607	3.69	0.000	5.21070	2.46868	2.25	0.025
Yolo1	3.27398	0.86103	3.80	0.000	3.30739	1.52614	2.12	0.034
$Yolo1^2$	-5.46467	0.79336	-6.89	0.000	-5.43591	1.38392	-3.97	0.000
SJR3	-1.25328	0.43049	-2.91	0.004	-1.25982	0.79535	-1.57	0.118
ExpIn1	9.14293	2.47953	3.69	0.000	9.06316	4.15507	2.22	0.027
$ExpIn1^2$	-6.64883	1.59365	-4.17	0.000	-6.58097	2.70343	-2.49	0.013
ExpSJR1	-4.25421	1.90226	-2.24	0.026	-4.24786	3.28664	-1.30	0.196
$ExpSJR1^2$	5.10067	1.59772	3.19	0.002	5.04304	2.73940	1.88	0.060
TExp2	6.41371	1.67739	3.82	0.000	6.20076	2.83604	2.34	0.020
$TExp2^2$	-6.46446	1.33352	-4.85	0.000	-6.24845	2.24489	-2.98	0.003
Secchi	-3.23758	0.58290	-5.55	0.000	-3.27384	0.94272	-3.40	0.001
CondTp	5.95032	1.86790	3.19	0.002	4.93108	2.89962	2.40	0.017
$CondTp^2$	-23.93597	4.37596	-5.47	0.000	-21.17724	5.90224	-4.52	0.000

[a]The significance of the t-value based on the standard large sample theory of linear modeling.
[b]The significance based on the bootstrap estimates of bias and standard error.

Table 4 Results from bootstrap sampling for the significance of estimated step effects. The significance based on the usual F-test of the individual regression coefficient is Sig. The significance level allowing for multiple testing is Sig1, with significance at the 1%, 5%, 10% and greater than 10% levels indicated by $p < 0.01$, $p < 0.05$, $p < 0.10$ and NS (not significant), respectively.

Period	Estimate	SE	F[a]	Sig	Sig1
1967-1968	-0.146	0.429	0.12	0.840	NS
1968-1969	-0.165	0.381	0.19	0.823	NS
1969-1970	0.644	0.393	2.69	0.398	NS
1970-1971	-0.653	0.277	5.55	0.244	NS
1971-1972	0.150	0.271	0.31	0.758	NS
1972-1973	0.117	0.236	0.25	0.809	NS
1973-1974	-0.261[b]	0.257	1.03	0.628	NS
1974-1975	-0.261	0.257	1.03	0.628	NS
1975-1976	0.572	0.325	3.10	0.366	NS
1976-1977	0.598	0.368	2.64	0.418	NS
1977-1978	0.907	0.353	6.60	0.188	NS
1978-1979	1.829[b]	0.300	37.07	0.002	$p < 0.10$
1979-1980	1.829	0.300	37.07	0.002	$p < 0.10$
1980-1981	-2.175	0.321	45.93	0.000	$p < 0.05$
1981-1982	-1.988	0.286	48.38	0.000	$p < 0.01$
1982-1983	-1.371	0.279	24.19	0.011	NS
1983-1984	-1.905	0.306	38.76	0.000	$p < 0.05$
1984-1985	0.827	0.315	6.88	0.167	NS
1985-1986	0.722	0.304	5.64	0.213	NS
1986-1987	1.487	0.363	16.81	0.042	NS
1987-1988	0.782	0.398	3.87	0.315	NS
1988-1989	0.381	0.347	1.20	0.580	NS
1989-1990	0.721	0.362	3.97	0.304	NS
1990-1991	1.488	0.367	16.43	0.037	NS
1991-1992	-0.128	0.361	0.13	0.873	NS
1992-1993	-0.083	0.331	0.06	0.902	NS
1993-1994	-1.400	0.365	14.70	0.055	NS
1994-1995	-0.350	0.385	0.83	0.674	NS
1995-1996	-1.370	0.251	29.90	0.002	NS
1996-1997	-0.303	0.253	1.43	0.544	NS
1997-1998	0.311	0.243	1.65	0.524	NS
1998-1999	1.391	0.237	34.36	0.006	$p < 0.05$
1999-2000	0.710	0.289	6.04	0.209	NS
2000-2001	-0.372	0.338	1.21	0.601	NS
2001-2002	-1.159	0.418	7.70	0.147	NS
2002-2003	-0.192	0.478	0.16	0.835	NS
2003-2004	-0.681	0.695	0.96	0.585	NS

[a]The F-value is Estimate/SE^2.

[b]Because there are no data for 1974 and 1979, exactly the same estimates are obtained for 1973-4 and 1974-5, and for 1978-9 and 1979-80.

Considering just the effects of the hydrological and variables, it can be seen that in general the t-values based on the bootstrap results are not as significant as the t-values from the original analysis of the data. In particular, the effect of SJR3 (San Joaquin River flow) is no longer significant ($p = 0.118$), the coefficient of ExpSJR1 (the total exports/San Joaquin River flow ratio) is no longer significant ($p = 0.196$), and the coefficient of $ExpSJR1^2$ is not quite significant at the 5% level ($p = 0.06$). Thus based on the bootstrap results some reassessment of the effects in the model is appropriate.

In Table 4 the estimates shown are of step-change effects for the period shown. For example, the first effect is between 1967 and 1968. These estimates apply if the single step change effect is added to the model defined in Table 3, so that only one possible step-change effect is ever considered. Two significance level from the bootstrap resampling are shown. The first is the probability of getting an F-value as large or larger than the one for the observed data by chance alone, if no step change actually occurred. There are ten effects that are significant at the 5% level from this point of view, but not the change from 2001 to 2002.

A more stringent assessment of significance that takes into account the large number of step-change parameters that can be estimated asks whether the F-value for a change point is significantly large in comparison to the distribution of the maximum F-value that is obtained for all change points when data are generated from the model described in Table 3, which has no change points at all. This distribution was estimated by recording the maximum F-value from all possible change points for each of the 1000 bootstrap samples. These maximum F-values were then ordered from the smallest to largest and the critical values for 1%, 5% and 10% significance were estimated by the values exceeded by 1%, 5% and 10% of this distribution. This then gave three changes that are significant at the 5% level (for 1980-1, 1983-4 and 1998-99), and one change significant at the 1% level (for 1981-2). This then suggests that the model of Table 3 needs to be reconsider in terms of the introduction of change point effects for 1981-2 and 1998-9.

Further Modifications to the Model

The analysis of the previous section suggested four potential changes to the null model assumed for estimating change point effects. These are:

! adding a step effect for 1981-2,

! adding a step effect for 1998-9,

! removal of the effect of SJR3, and

! removal of one or both of the effects of ExpSJR1 and $ExpSJR1^2$, These changes were initially investigated using ordinary log-linear modeling and then the results checked with a further bootstrap analysis.

Adding a step effect variable for 1981-2 (Step81) into the equation resulted in an extremely significant improvement in the fit of the equation (F = 48.53 with 1 and 465 df, $p < 0.001$). Adding in a step effect variable for 1998-9 (Step98) then resulted in an even more significant improvement in the fit of the equation (F = 87.75 with 1 and 464 df, $p < 0.001$). Because these effects were found to be significant from a bootstrap analysis even allowing for multiple testing they are assumed to represent real changes to the population numbers.

Removing the term $ExpSJR1^2$ from the equation gave no significant change in the fit (F = 0.96 with 1 and 465 df, p = 0.328). Removing SJR3 also gave no significant change (F = 1.38 with 1 and 466 df, p = 0.241). At that stage the coefficient of ExpSJR1 was very significant so this term was not removed from the equation.

When a step effect for 2001-2 was added into the equation at that point the coefficient was quite small (-0.174) and the improvement in fit was not at all significant (F = 0.20 with 1 and 465 df, p = 0.656). Hence according to this model there is no evidence of a step change at that time. The effect was therefore removed from the model.

To check the validity of the equation at this stage 1,000 bootstrap sets of data were generated assuming that the model is correct. This was to verify that there are no serious biases in the estimated coefficients and that the standard errors used to assess the significance of coefficients are reasonably accurate. The results are summarized in Table 5.

The bootstrap results indicate that the model being assumed is reasonable. Some of the estimated area effects are unstable because of very low or zero counts, which has resulted in bootstrap sets of data with no fish in an area. Generally the significance of the other effects is confirmed, although the most quartic coefficient of the trend is not significant according to the bootstrap results. This term could therefore be removed, but this was not considered necessary at this stage.

A comparison between the observed counts of delta smelt and those expected from the fitted model are shown in Figure 7. The fit of this model is distinctly better than the fit of the model considered before, and this shows up to some extent in a comparison of Figure 7 with Figure 5.

Table 5 Estimates of the modified log-linear model. The estimates on the left are for the log-linear model fitted to the data. The values on the right are the mean and standard errors (SE) of estimates obtained when 1000 bootstrap sets of data were generated using the parameter estimates on the left. The bootstrap values indicate the bias (if any) in estimation, and the standard errors that are actually obtained by the fitting process. The t-values on the right are corrected for any biases in the estimation of a parameter and its standard error.

	Log-linear Model				Bootstrap Values			
Parameter	Estimate	SE	t	Sig[a]	Mean	SE	t	Sig[b]
Constant	-2.36400	1.57600						
Area 3	1.41182	2.18481	0.65	0.518	1.12207	1.99118	0.86	0.393
Area 4	2.21362	1.56209	1.42	0.157	2.08974	1.26282	1.85	0.065
Area 5	1.33333	1.75934	0.76	0.449	1.06002	1.60650	1.00	0.318
Area 7	0.46563	4.11898	0.11	0.910	-3.47822	4.89176	0.90	0.368
Area 8	-5.66455	58.38091	-0.10	0.923	-6.12199	1.42332	-3.66	0.000
Area 10	2.63014	1.39374	1.89	0.060	2.52650	1.10117	2.48	0.013
Area 11	0.35365	1.35016	0.26	0.793	0.24938	1.07445	0.43	0.670
Area 12	0.56026	1.31955	0.42	0.671	0.52885	1.02557	0.58	0.564
Area 13	0.83666	1.32433	0.63	0.528	0.84844	1.06269	0.78	0.438
Area 14	1.07453	1.32240	0.81	0.417	1.08308	1.05614	1.01	0.314
Area 15	0.74950	1.34917	0.56	0.579	0.77350	1.16920	0.62	0.535
Area 16	-0.66981	1.35593	-0.49	0.622	-0.66891	1.19807	-0.56	0.576
Area 17	-2.60789	1.41568	-1.84	0.066	-2.60792	1.28806	-2.03	0.043
T1	0.25223	0.02109	11.96	0.000	0.26053	0.03697	6.60	0.000
T2	-0.00363	0.00191	-1.91	0.057	-0.00350	0.00340	-1.11	0.268
T3	-0.00084	0.00007	-11.72	0.000	-0.00087	0.00013	-6.53	0.000
T4	-0.00002	0.00001	-2.83	0.005	-0.00002	0.00001	-1.56	0.119
Sac1	3.91009	1.14575	3.41	0.001	4.17249	2.11333	1.73	0.085
Yolo1	5.91782	0.73950	8.00	0.000	6.01828	1.32745	4.38	0.000
Yolo1^2	-5.60056	0.68338	-8.20	0.000	-5.78751	1.21115	-4.47	0.000
ExpIn1	8.99082	1.75823	5.11	0.000	9.42548	3.24518	2.64	0.009
ExpIn1^2	-6.50875	1.03546	-6.29	0.000	-6.76600	1.89026	-3.31	0.001
ExpSJR1	2.69041	0.49492	5.44	0.000	2.68614	0.87546	3.08	0.002
TExp2	4.37548	1.39840	3.13	0.002	4.48460	2.46456	1.73	0.084
TExp2^2	-4.81652	1.11964	-4.30	0.000	-4.93863	1.97034	-2.38	0.018
Secchi	-2.39046	0.50897	-4.70	0.000	-2.53803	0.86198	-2.60	0.010
CondTp	-2.01031	1.63841	-1.23	0.220	-2.40688	2.71101	-0.60	0.552
CondTp^2	-13.88687	3.52576	-3.94	0.000	-12.83552	4.93391	-3.03	0.003
Step81	-2.81508	0.26347	-10.68	0.000	-2.87490	0.48367	-5.70	0.000
Step98	2.21258	0.22279	9.93	0.000	2.23042	0.41457	5.29	0.000

[a]The significance of the t-value based on the standard large sample theory of linear modeling.
[b]The significance based on the bootstrap estimates of bias and standard error.

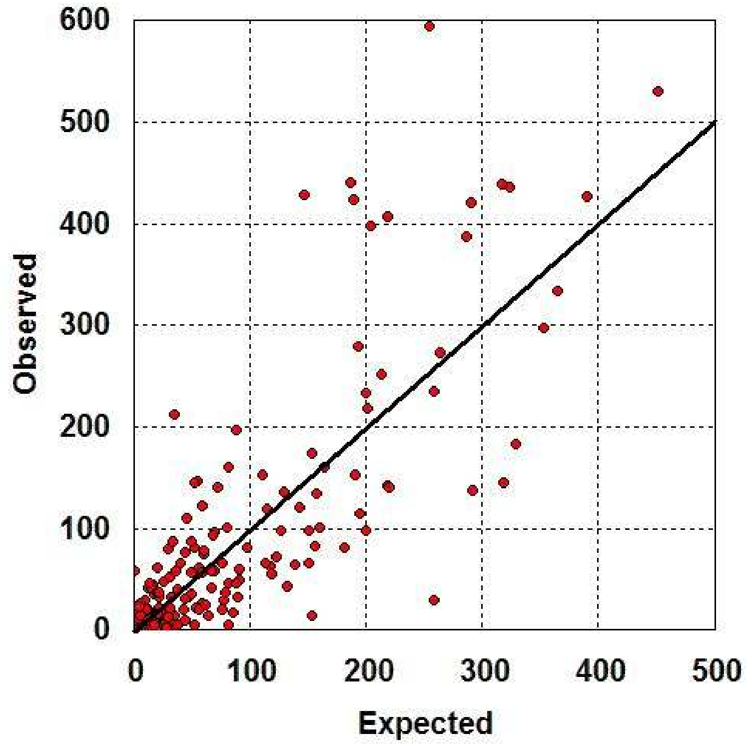

Figure 7 Comparison between the observed catches of delta smelt and the values predicted by the model that includes step effects between1981-82 and 1998-99.

The estimated effects of the hydrological and environmental variables included in the new model are shown in Figure 8. These are fairly similar to the effects estimated from the log-linear model fitted before (Figure 3) although the estimated effects are all changed to some extent.

Figure 9 shows how the estimated effects combine to produce the expected CPUE values for sampling area 15 in all of the years. This is the area used before to produce Figure 4 because it is one of the areas with fairly high observed and expected counts. The hydrological variables and their effects for this area will be the same as those in the other areas. The step effects will also be the same in other areas, but the conductivity and Secchi effects are area specific.

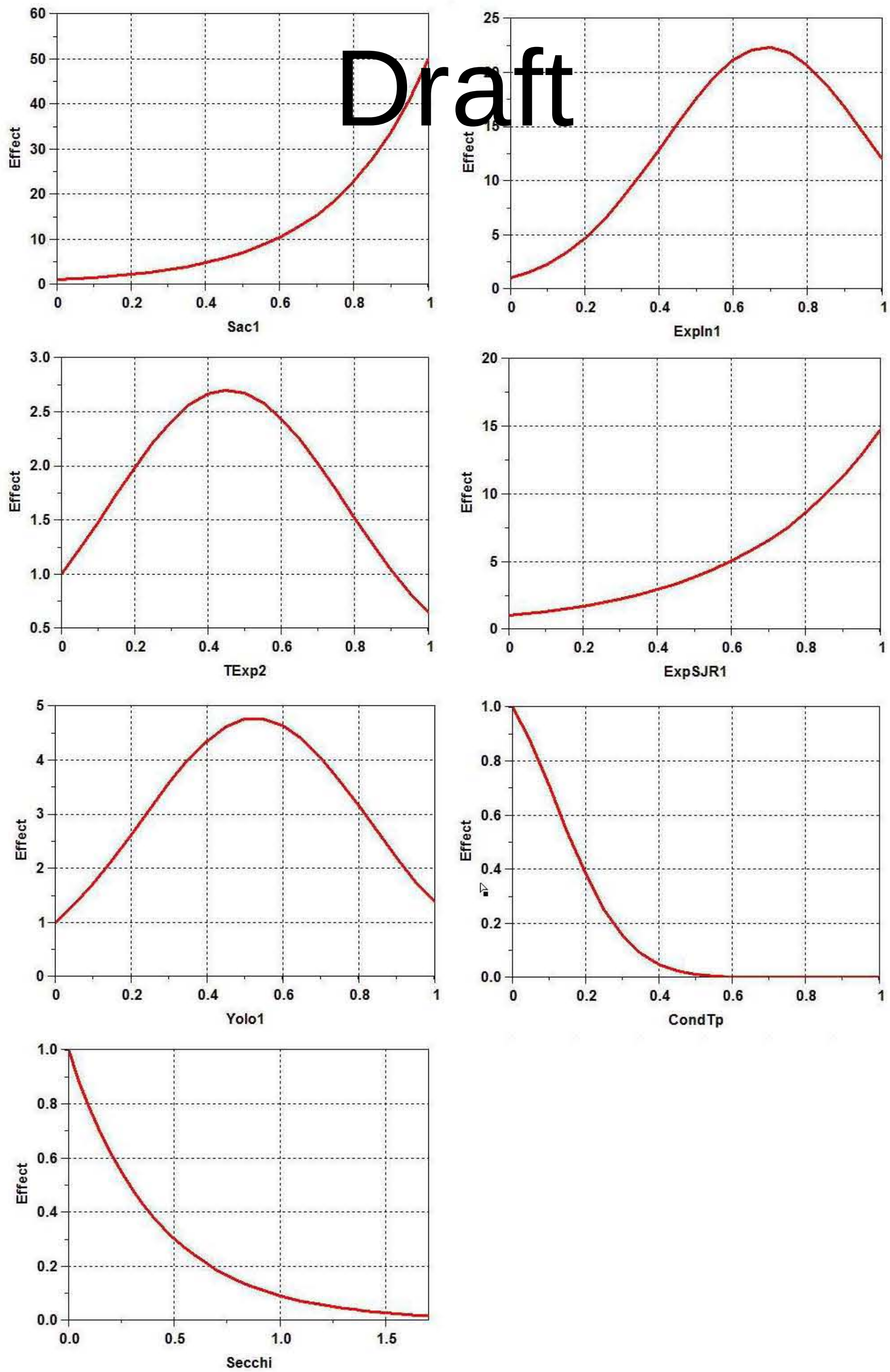

Figure 8 Estimated effects of hydrological and environmental variables in the modified log-linear model for delta smelt counts.

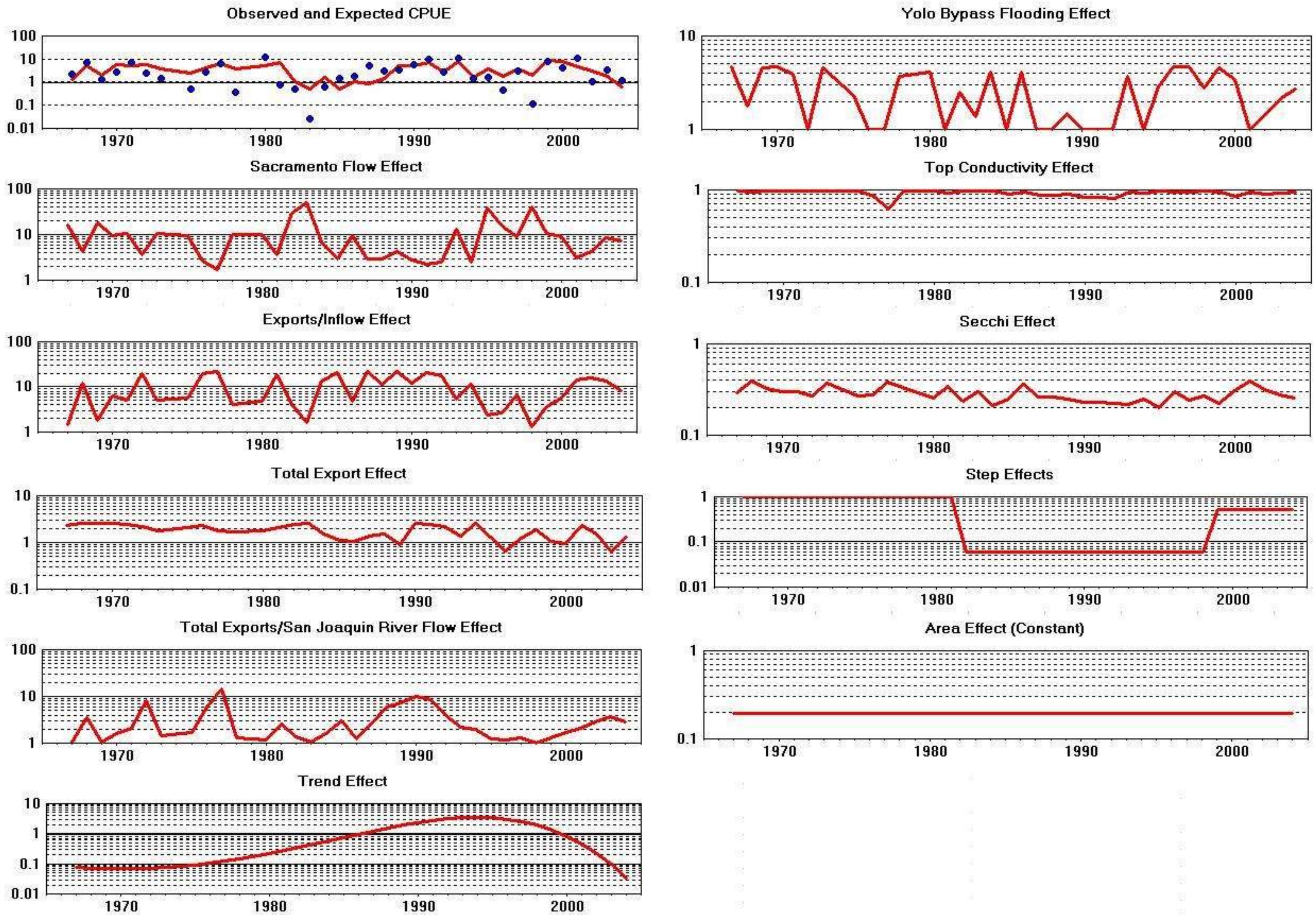

Figure 9 The observed and expected CPUE for delta smelt in area 15, with the multiplicative effects that make up the CPUE, i.e., the expected CPUE is found by multiplying together all of the effects for the year being considered.

Discussion

It seems from the analyses considered here that there is little evidence for a step change in delta smelt numbers between 2001 and 2002, but a good deal of evidence for a step change downwards between 1981 and 1982 and a step change upwards between 1998 and 1999. The downward change is estimated to be a multiplication of the numbers by exp(-2.850) = 0.058, while the upward change is estimated to be a multiplication of numbers by exp(2.161) = 8.680. The two estimated changes combined then give a multiplication by 0.058x8.680 = 0.502. However, these apparent changes need to be interpreted taking into account the estimated trend of increasing numbers from 1975 to 1994, followed by decreasing numbers.

Caution is also needed in the interpretation of the effects of the hydrological variables. There are many high (positive and negative) correlations between these, as shown in Table 1. This means that other combinations of the variables, with other coefficients in the fitted equation, may predict the delta smelt numbers about as well as the combination estimated here. Furthermore, because the data are observational the estimated effects represent associations that have apparently existed in the past, but that are not necessarily causal.

References

Manly, B.F.J. (2005a). *Analyses A: Log-Linear Modeling, Linear Regression, and Principal Components Analysis for Fall Midwater Trawl Fish Counts, 1967-2004*. Western EcoSystems Technology, Cheyenne, Wyoming.

Manly, B.F.J. (2005b). *Analyses C: Change Point Analyses of the Fall Mid-Water Trawl and the Bay Study Fish Counts*. Western EcoSystems Technology, Cheyenne, Wyoming.